Promoting Sustainable Intensification of African Indigenous Vegetable Production in Kenya

DISSERTATION

zur Erlangung des akademischen Grades

“Doktor rerum agriculturarum”

im Fach Agrarwissenschaften

(Dr. rer. agr.)

eingereicht an der
Lebenswissenschaftlichen Fakultät
der Humboldt-Universität zu Berlin

von

Barnabas Kiplagat Kurgat

Präsidentin der Humboldt-Universität zu Berlin:
Prof. Dr.-Ing. Dr. Sabine Kunst
Dekan der Lebenswissenschaftlichen Fakultät:
Prof. Dr. Bernhard Grimm

Gutacher: 1. Prof. Dr. Hermann Lotze-Campen
2. Prof. Dr. Benjamin K. Mutai
3. Prof. Dr. Christof Engels

Tag der Wissenschaftlichen Aussprache: 18.10.2018

Table of Contents

This thesis is dedicated to my family

Chapter 1

General introduction

1.1 Importance of and challenges facing agriculture in Sub-Saharan Africa

Agriculture remains a significant driver of economic development, food security and farmers' livelihood advancement in Sub-Sahara Africa (SSA) (AGRA, 2017). On average, agriculture contributes approximately 15% to the total gross domestic product (GDP) of countries in SSA, and employs more than half of the total labour force (IMF, 2012; OECD/FAO, 2016). In Kenya, the sector generates 32.4% directly and another 20.7% indirectly (through value chain linkages such as manufacturing, distribution and other service related sectors) to the total GDP and employs 75% of the labour force (KIPPRA, 2017). Noteworthy is horticulture, the fastest growing agricultural sub-sector in Kenya, which accounts for 34% of total agricultural output and employs about 6 million people (GoK, 2010). Approximately, 95% of total horticultural produce are consumed locally or traded at domestic markets while 5% are exported (GoK, 2011). The leading horticultural crops in terms of value are vegetables, flowers and fruits, accounting respectively for 36%, 30% and 26% of the total domestic value of horticultural output (HCDA, 2014). The sector also plays an important role in enhancing food security, poverty alleviation and provision of raw materials for agro-processing industries (GoK, 2010; HCDA, 2014). However, agriculture is at the same time faced with a number of challenges: such as rising food demand from the growing and increasingly affluent population, rising urbanisation, declining soil fertility and climate change (Thornton, et al., 2011; Tilman and Clark, 2014; Vanlauwe et al., 2017).

Sub-Sahara Africa accounts for approximately 13% of the global population (950 million) and this share is projected to increase to almost 22% or 2.1 billion by 2050 (United Nations, 2015; OECD/FAO, 2016). Population in urban cities of countries in SSA is also estimated to triple by 2050 (United Nations, 2014). Similarly, Kenya's overall population is expected to increase from 40 million in 2010 to 95 million by 2050, while urban population is anticipated to rise by 46%, up from 9 million in 2010 to 42 million by 2050 (FAO, 2016). These changes will undoubtedly influence agricultural production, farmers' livelihoods, food security, and the environment under which the aforementioned depends on. Whereas the full effects of these changes are yet to be felt, there is evidence that population pressure have already caused gradual shrinking of farm sizes over time. For instance, Heady and Jayne, (2014), found out that the average farm size have shrunk by 30-40% since 1970s in land constrained countries[1] in SSA. Consequently, in response to this shrinking farm size,

[1] According to Fuglie and Rada (2013), land constrained countries as those countries with population per square km of agricultural land greater than 100 people.

smallholder farmers have responded by cropping their farms continuously with very limited or even no fallow periods. For example, fallowed land as a proportion of total farmland in SSA has declined from 40% in 1960 to about 15% in 2011 (Fuglie and Rada, 2013).

Continuous mono-cropping with low soil nutrient inputs have been cited in literature as the main cause of soil degradation in SSA (Tittonell and Giller, 2013; Vanlauwe et al., 2014). Declining soil nutrient balance (soil mining) is the most common form of soil degradation (Tittonell, 2003). This problem of soil mining is widely spread across many farmlands in SSA and is a phenomenon that has been going on in the past 2.5 decades (Baijukya et al., 2005; Zingore et al., 2007). For instance, soil mining was reported in western Kenya way back in the 1990s by Smaling et al. (1993). This study reported average annual net mining of 42 kg nitrogen, 3 kg phosphorous and 29 kg potassium per hectare. A decade later, Tittonell et al. (2005) reported similar problems of mining soil nitrogen in the range of 17-24 kg per hectare per season in western Kenya. Soil mining constraints crop productivity, biomass production and reduces soil cover, which in turn, accelerates other soil degradation process, such as soil acidification, soil erosion and loss of organic matter (Vanlauwe et al., 2015; AGRA, 2016). Mono-cropping also leads to loss of agro-biodiversity, which is a vital component in improving soil fertility, enhancing food security, and building the resilience of agricultural production systems to climate risks and other biotic stress factors such as pest and diseases (Jacobsen et al., 2015). Low soil fertility and loss of agro-biodiversity decreases crop productivity, and exacerbates food insecurity and poverty particularly in rural areas of SSA (Sanchez, 2002; Marenya and Barrett, 2009).

Climate change also poses substantial threat to current agricultural production systems and livelihoods of many farmers in SSA (Müller et al., 2011; IPCC, 2014). This is because most African smallholder agricultural production systems depend on rain-fed farming, which is highly vulnerable to climate change-related stress/shocks (seasonal shift in rainfall events and occurrence of extreme weather events such as droughts) (Lotze-Campen, 2011; IPCC, 2014). At the same time, smallholder managed agricultural fields are the main source of agricultural greenhouse (GHG) emissions in SSA (Kim et al., 2016; Pelster et al., 2017). Nitrous oxide (N_2O) is the major form of GHG emitted from smallholder agricultural production systems. In total, Africa contributes 16.4% of the world's N_2O emissions, out of which 42% is from agriculture (Hickman et al., 2011). Use of chemical fertilisers and animal manure for crop production are the main sources of agricultural N_2O emission (Syakila and Kroeze, 2011). With projected population trends, which are expected to increase food demand, the importance of fertiliser use in agricultural production in SSA is also expected to rise as well. This may in turn cause an increase in N_2O emissions by comparison to the present levels, if sustainable agricultural practices are not adhered to.

The compounded effects of rising population and urbanisation, declining soil fertility, and the changing climate is likely to intensify the existing problems of food insecurity, undernutrition and poverty in SSA. Latest statistics indicates that already more than 60% of the rural population lives on less than US$ 1.25 a day (IFAD, 2011). In addition, 20% of the population is on average food-insecure (Wheeler and von Braun, 2013). This is also true for Kenya, where about 10% of the population live in a chronic state of food insecurity and acute malnutrition (UNDP, 2012). This chronic state of food insecurity is even high for Kenyan children under 5 years. For instance, it has been reported that 35% of the children under 5 years are being stunted (Matanda et al., 2014). Conclusively, the main issue is to address a combined challenge to increase agricultural production to meet the rising food demand, reduce malnutrition, enhance food security and eradicate poverty, while at the same time protecting the environment.

1.2 Sustainable agricultural intensification

Sustainable intensification (SI) of agricultural production has been cited as one potential pathway to address these multiple challenges (Pretty, 1997; Garnett and Godfray, 2012; Cook et al., 2015). SI concept was first coined in the 1990s and was defined as an approach of intensifying agricultural production on existing land area while protecting the environment (Pretty, 1997). Other authors have described SI as a process to simultaneously increase agricultural output per unit land area, resource use efficiency, natural capital and flow of environmental services while reducing environmental impacts, such as GHG gas emissions (The Royal Society, 2009; Godfray et al., 2010). The Montpelier Panel Report (2013), further widen the SI concept to include social and economic sustainability as well as human wellbeing. In addition, given the need for increased climate-friendly food production, SI has recently been considered as one component of sustainable food systems framework (Garnett and Godfray, 2012; Cook et al., 2015). A number of agricultural practices have been listed in literature as indicative of SI practices (SIPs) and mainly include among others: use of hybrid (modern) seeds, crop system diversification, intercropping, crop rotation, crop residue retention, use of organic fertilisers, minimum tillage, integrated soil fertility management, irrigation/ water harvesting and agro-forestry (Dile et al., 2013; The Montpelier Panel Report, 2013; Folberth et al., 2014; Vanlauwe et al., 2014). The benefits of practising these SIPs include improved yields, improved nitrogen use efficiency, increased farm income, and resource conservation (Pretty et al., 2011; Teklewold et al., 2013; Pretty, 2014). Despite the aforementioned benefits of adopting SIPs and concerted efforts to promote their uptake, the adoption and diffusion rates still remain low in SSA (Ayaji et al., 2007; Giller et al., 2009; Teklewold et al., 2013; The Montpellier Panel Report, 2013).

Previous studies have examined drivers and barriers of SIPs so as to recommend potential pathways to promote their uptake (Marenya et al, 2007; Kassie et al., 2013; Teklewold et al., 2013; Kassie et al., 2015; Ndiritu et al., 2014). Results from these studies indicate that household socio-economic factors, plot level characteristics and institutional factors influence their adoption. Few other researchers have assessed the impacts of adoption on farmer's livelihoods and their findings shows positive effects, but the magnitude of the impact varies. For instance, Methange et al. (2014) found that adoption of hybrid maize seed in Kenya, increased household income, asset value and reduced poverty by 7%, 9% and 2.9% respectively. Shiferaw et al. (2014) also illustrated that adoption of improved wheat varieties increase household food security by about 2.7 – 8.6% and reduces probability of chronic food insecurity in the range of 1.3 – 5.9% in Ethiopia. However, all these studies were mainly from smallholder cereal crop production systems in rural areas with no consideration of adoption of SIPs and their impacts from vegetable production as well as peri-urban[2] production environments. Thus, while we increasingly know what determines adoption of interrelated SIPs in cereal crop cultivation, determinants of adoption of SIPs in vegetable production and their impacts on famer's livelihoods are uncertain. Similarly, it is not known whether there is any significant difference between the extent of adoption in peri-urban and rural areas. There may be difference because peri-urban farmers may have more access to better transport network, input-output markets, as well as credit and extension services, hence fostering adoption. On the other hand, peri-urban areas are more likely to offer good off-farm work opportunities with higher wages possibly making it difficult for farmers to adopt labour intensive SIPs, unless they also provide high returns on labour.

Furthermore, environmental impacts (GHG gas emissions) from adoption of SIPs in vegetable production as well as livelihood and environmental or climate trade-offs is also poorly understood. The need to have a clear understanding of the livelihood and climate trade-offs is because yields are only a small fraction of what drives farmers' decision making. This is because yield increase does not always increase net farm revenue due to occasionally high input costs (Pimentel et al., 2005). Past studies have ignored this important aspect, which is

---

[2] Following Drechsel et al. (2006), peri-urban is used in this study to refer to cultivation of vegetables in areas within 30 - 40 km from urban centres or cities.

useful in developing or selecting soil fertilisation strategies that optimise both livelihoods and environmental outcomes. Earlier studies from vegetable fields in SSA are limited in number and only measure N_2O emissions per unit land area (Predotova et al., 2010; Lompo et al., 2012; Rosenstock et al., 2016). Those containing N_2O emissions measurement and yields are mainly from cereal crops and have no economic data to help estimate livelihood and environmental trade-offs (Nyamandzawo et al, 2014; Hickman et al., 2014; Kim et al., 2016; Pelster et al., 2017).

Vegetables production is the leading sub-sector of horticulture in Kenya (HCDA, 2014). Vegetables, especially African indigenous vegetables (AIVs)[3] plays a crucial role in enhancing food security, nutritional and health status, generating household income for both rural and urban populations (Abukutsa-Onyango, 2003; Ngugi et al., 2007; Uusiku et al., 2010; Muhanji et al., 2011). For example, fresh leaves from amaranth (*Amaranthus cruentus*), slender leaf (*Crotalaria brevidens*), cowpea (*Vigna unguiculata*) and spider plant(*Cleome gynandar)* contain more than 100% of the recommended daily allowance (RDA) for vitamins and minerals as well as 40% of RDA proteins for growing children and lactating mothers (Schippers, 2000; Abukutsa, 2003). Due to the rising consumer consciousness on the nutritional and health benefits of these AIVs, their demand has risen in the recent past and they are now traded in various market outlets in Kenya fetching premium prices (Chelang'a et al., 2013). Consequently, land area allocated to AIV production in Kenya increased by 31%, up from 27,102 ha in 2009 to 35, 503 ha in 2014 (HCDA, 2014). Similarly, AIV produce (yields) and value increased respectively by 6% and 10% in 2014 compared to what was obtained in 2012 (HCDA, 2014). Despite this increase in land area allocation and yields, AIV supply does not match market demand particularly during dry periods. For instance, Muhanji (2011) reported an AIV supply deficit of up to 60% in Kenya during dry periods. This is partly due to increasing water scarcity to support year round production of AIVs, declining soil fertility, lack of good quality seeds and knowledge on best agronomic practices, and market barriers (Onium and Manikin, 2008; Abeokuta et al., 2010; Muhanji et al., 2011; Croft, et al., 2016), challenges which SI aims to address. This supply deficit is likely to widen given the projected population increase and rising prosperity. It is therefore, important to promote sustainable intensification of AIV production to meet this growing AIV demand, while at the same time maintain or even improve soil fertility and protect the environment. This study therefore,

[3] The meaning of African indigenous vegetables (AIVs) used in this study was taken from Schippers (2000), who defined indigenous vegetables as those whose primary or secondary centre of origin is in the respective location: here, Africa or Kenya.

sought to examine the extent and factors influencing adoption of SIPs in AIV production and the resulting impacts of adoption on farmers' livelihoods and the environment. The SIPs considered were: improved irrigation systems[4], integrated soil fertility management[5], organic or animal manure and AIV diversification.

1.3 Objectives

The objective of this study was to examine the extent and factors influencing adoption of SIPs in smallholder AIV production and evaluate its impacts on farmers' livelihoods and the environment. To achieve the goal of this study, the following specific questions were addressed:

1.4 Research questions

1. (a) What is the extent of adoption of SIPs in Kenyan rural and peri-urban AIV production? (b), Are there differences between rural and peri-urban areas? (c), which factors influence adoption? and, (d) which, if any, of the interrelated SIPs complement or substitute one another?
2. What is the impact of adoption of SIPs on smallholder farmers' livelihoods?
3. Which soil fertility management strategy optimises livelihoods and climate trade-offs in Kenyan peri-urban AIV production?

1.5 Conceptual framework

Farmers' decision to use SIPs in AIV production is influenced by socio-economics, physical, institutional and environmental factors as illustrated in the decision-making framework in Fig.1.1. This conceptual framework was adopted and modified from sustainable livelihood framework as indicated by Shiferaw et al. (2007), which recognizes and places household investment decisions in the context of local, national or regional changes (population pressure, urbanisation, polices and institutions).

[4] Is described here as the use of hosepipe-sprinklers fitted with electric, petrol or diesel driven-motorised pumps for pumping water from wells and rivers to vegetable fields

[5] Also refereed as mixed, is described here as a combined application of organic and inorganic manure

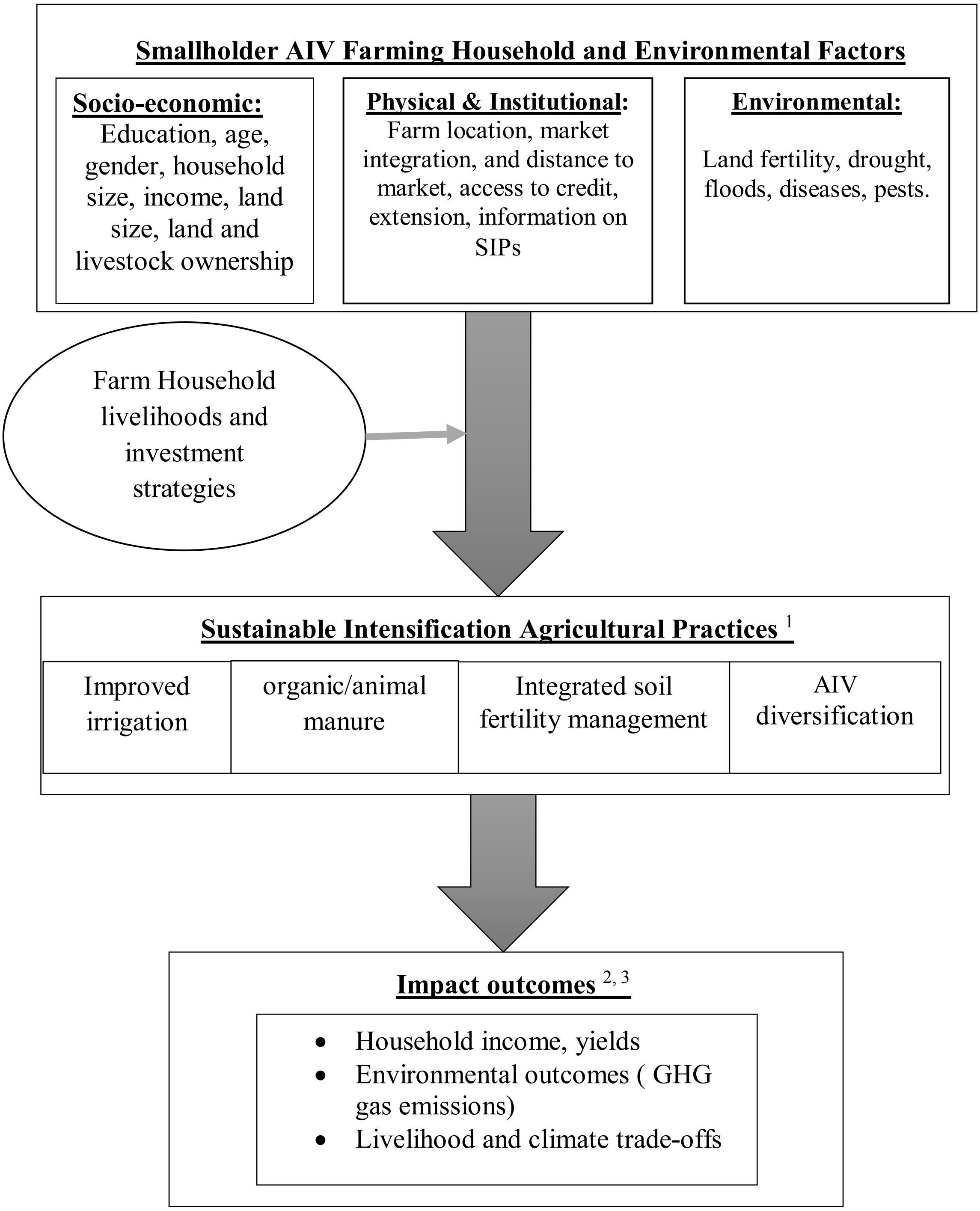

Figure 1.1.Conceptual framework (adopted and modified from Shiferaw et al., 2007).

[1, 2, 3] denotes output in form of paper 1, 2, 3 respectively.

This study assumes that smallholder AIV farmers' attempts to maximize their livelihoods benefits based on the existing household resources and expected environmental shocks or constraints that jointly determine their vulnerability. Therefore, adoption or non-adoption of SIPs, household income (livelihoods) as well as environmental outcomes were taken in this study as dependent variables. The magnitude of this dependent variables depends on farm household decisions on how much household assets are allocated for adoption of SIPs.

1.6 Study locations

This study was carried out within the framework of HORTINLEA[6] research project (see http://www.hortinlea.org/ for detail project description). Four counties in Kenya were the central focus. These counties were Kiambu and Nakuru located in peri-urban areas and Kakamega and Kisii counties, which are located in rural areas of western Kenya. They were chosen because they are the major areas where AIVs are cultivated and traded.

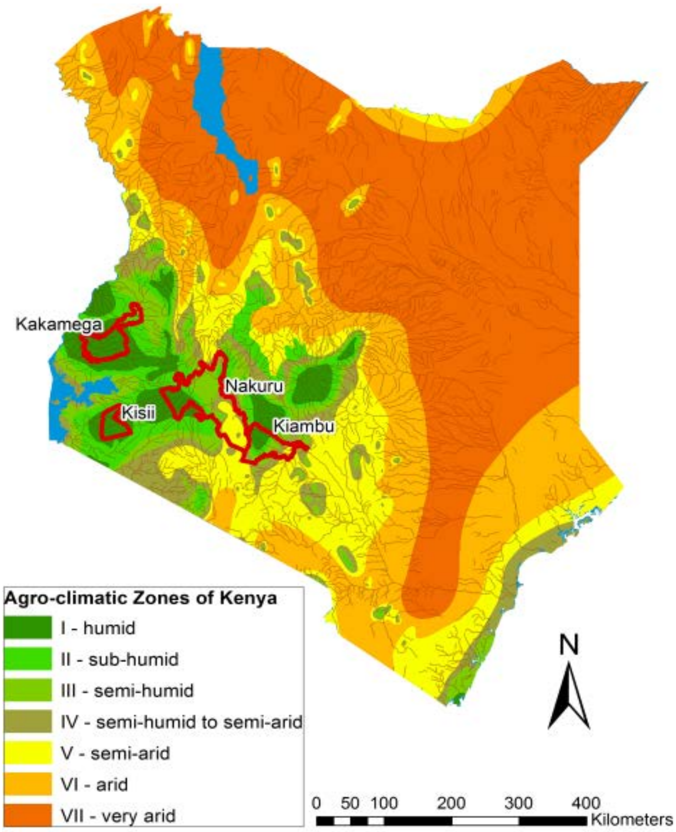

Figure 1.2. Map of Kenya showing the four counties where the data was collected.

Kakamega County has nine sub-counties and covers approximately 3,225 square km and has an altitude of 1,535 m. The county receives annual rainfall ranging from 1,200 to 2000 mm, and a maximum and minimum temperature of 27 °C and 14°C respectively and has a population of about1.7 million people. Kisii County has also nine sub-counties, and covers a land area of 1,302 square km and altitude of 1,700 metres. The county annual rainfall of 2,070 mm and a maximum and minimum temperature of 25°C and 15°C respectively and has a

[6] Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa

population of 1.2 million people (KNBS, 2009). These two counties are generally categorized into humid and sub - humid agro-climatic zones of Kenya and AIV production in these counties is mainly rain-fed and is cultivated in two production seasons (long rainy season – March to July and short rainy season – September to December) in year.

Nakuru County has 11 sub-counties and covers 7,509 square km with an altitude of 1,795 m. On average, the county receives annual rainfall and mean temperature of 960 mm and 17.5°C (maximum 25°C and minimum 11°C) respectively, and has population of 1.6 million people. Kiambu County on the other hand is divided into 12 sub-counties and covers a total land area of 2,450 square km and has an altitude 1940 m and a population of 1.6 million people (KNBS, 2009). The county has a maximum and minimum average monthly temperature of 23.8°C and 12.6°C respectively. Production of AIVs in these two counties is partly rain-fed as well irrigated (mainly during driest periods). Additionally, vegetables produced are sold locally (farm gate) as well in to the nearby open urban markets, retail shops, restaurants and supermarkets.

1.7 Data sources and methods

The summary of data source and the methods of data analysis are presented in table 1.1. Detail description of these data sources and methods are found in the respective chapters.

Table 1.1. Summary of data sources and methods of analysis

Issues investigated	Source of data	Method of data analysis
Assessment of adoption of SIPs	HORTINLEA survey of 2016	Multivariate probit (MVP) model
Evaluation of impacts adoption of SIPs on farmers' livelihoods	HORTINLEA survey of 2016	Treatment effect Model
Measurement of N_2O emissions	On-farm trials (experiment)	Gas chromatography
	Survey of case study farms	Linear interpolation
Determination of livelihood and climate trade-offs		Gross Margin (GM) Analysis

1.7 Thesis outline

Subsequent to **Chapter 1** that presents the general introduction, **Chapter 2** presents results and discussions on the extent and the household socio-economic, market, institutional and environmental factors influencing adoption of SIPs in smallholder AIV production systems using multivariate probit (MVP) model. The chapter also highlights the possible simultaneous adoption decisions as well as complementarities and substitutabilities between SIPs. **Chapter 3** gives the results of causal effects of adoption of SIPs on crop and total household income – proxy indicators used here for farmers' livelihoods- using treatment effect model. **Chapter 4** presents the results of on-farm soil fertility trails, which were established in peri-urban vegetable production areas of Kiambu for the purpose of quantifying N_2O emissions using static chambers/gas chromatography. Three soil fertility management strategies were tested; integrated soil fertility management and use of animal manure (categorised as SIPs) and use of inorganic fertiliser (diammonium- DAP) and no nitrogen input (control) for comparative purposes. The chapter also presents the economic performance of each of these soil fertility strategies as well as livelihood climate-trade-offs. Finally, **Chapter 5** gives a summary of the major findings integrating them into a general discussion of their practical implications for sustainable intensification of smallholder AIVs production in Kenya. The chapter finalizes with the main conclusion of the study along with recommendations for further research.

Reference

Abukutsa-Onyango, M. O. (2003). Unexploited potential of indigenous African vegetables in Western Kenya. *Maseno Journal of Education Arts and Science*, *4*(1), 103-122.

Abukutsa-Onyango, M. O. (2010). African indigenous vegetables in Kenya: Strategic repositioning in the horticultural sector. Inaugural Lecturer, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. April 30th 2010.

Ajayi, O. C., Akinnifesi, F. K., Sileshi, G., & Chakeredza, S. (2007). Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. *Natural Resources Forum*, 31, 306–317.

Alliance for a Green Revolution in Africa (AGRA) (2017). *Africa Agriculture Status Report: The Business of Smallholder Agriculture in Sub-Saharan Africa*. Nairobi, Kenya: Issue No. 5.

Alliance for a Green Revolution in Africa (AGRA) (2016). *Africa Agriculture Status Report: Progress towards agricultural transformation in Africa*. http://reliefweb.int/sites/reliefweb.int/files/resources/assr.pdf, Accessed date: 26th January 2018.

Baijukya, F. P., de Ridder, N., Masuki, K. F. & Giller, K. E. (2005). Dynamics of banana-based farming systems in Bukoba District, Tanzania: changes in land use, cropping and cattle keeping. *Agriculture Ecosystems and Environment*, 106, 395–406.

Chelang'a, P., Obare, G., & Kimenju, S. (2013). Analysis of urban consumers' willingness to pay a premium for African Leafy Vegetables (AIVs) in Kenya: a case of Eldoret Town. *Food security, 5*(4), 591-595.

Cook, S., Silici, L., Adolph, B., & Walker, S. (2015). *Sustainable intensification revisited*. IIED Issue Paper. IIED, London, pp 1-32.

Croft, M. M., Marshall, M. I., & Hallett, G. S. (2016). Market Barriers Faced by Formal and Informal Vendors of African Leafy Vegetables in Western Kenya. *Journal of Food Distribution Research, 47*(3), 49-60.

Dile, Y. T., Karlberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agriculture, Ecosystems & Environment,* 181, 69-79. doi:10.1016/j.agee.2013.09.014

FAO. (2016). FAOSTAT online database, Rome, Italy.

Folberth, C., Yang, H., Gaiser, T., Liu, J., Wang, X., Williams, J., & Schulin, R. (2014). Effects of ecological and conventional agricultural intensification practices on maize yields in sub-Saharan Africa under potential climate change. *Environmental Research Letters, 9*(4), 044004. doi:10.1088/1748-9326/9/4/044004

Fuglie, K., & Rada, N. (2013). Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa. *Economic Research Report* 145, USDA Economic Research Service, Washington, DC.

Garnett, T. & Godfray, C. (2012) Sustainable intensification in agriculture: navigating a course through competing food system priorities. Food Climate Research Network and the Oxford Martin Programme on the Future of Food. Oxford University, UK.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23-34. doi:10.1016/j.fcr.2009.06.017

Godfray, C., Beddington, J., Crate, R., Haddah, L., Lawrence, D., Muir, J., Pretty, J., Robison, S., Thomas, S., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science* 327: 812–818.

Government of Kenya (GoK). (2011). National horticulture policy. Republic of Kenya, Ministry of Agriculture. Government printers, Nairobi, Kenya.

Government of Kenya (GoK). (2012). National horticulture policy. Republic of Kenya, Ministry of Agriculture. Government printers, Nairobi, Kenya.

HCDA. (2014). National horticulture validated report. Kenya: Ministry of Agriculture, Department of Horticultural Crops Development Authority, Nairobi, Kenya.

Headey, D. D., & Jayne, T. S. (2014). Adaptation to land constraints: Is Africa different? *Food Policy, 48*, 18-33. doi:10.1016/j.foodpol.2014.05.005

Hickman, J., E., Havlikova, M., Kroeze, C. & Palm, C.A. (2011). Current and future nitrous oxide emissions from African agriculture. *Current Opinion in Environmental Sustainability* 5, 370–378.

Hickman, J. E., Palm, C. A., Mutuo, P., Melillo, J. M., & Tang, J. (2014). Nitrous oxide (N_2O) emissions in response to increasing fertilizer addition in maize (Zea mays L.) agriculture in western Kenya. *Nutrient Cycling in Agroecosystems, 100*(2), 177-187. doi: 10.1007/s10705-014-9636-7

IFAD. (2011). Rural Poverty Report: New Realities New Challenges. New Opportunities for Tomorrow's Generation. IFAD, Rome, pp. 332.

IMF (International Monetary Fund). (2012). International Jobs Report, Economist Intelligence Unit, Washington, DC.

IPPC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Group I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (core Writing Team, Pachauri, R., K. & Meyer, L., A. (Eds.). IPPC, Geneva, Switzerland, 151 pp.

Jacobsen, S., E. Sørensen, M., Pedersen, S. M., & Weiner, J. (2015). Using our agrobiodiversity: plant-based solutions to feed the world. *Agronomy for Sustainable Development, 35*(4), 1217-1235. doi: 10.1007/s13593-015-0325-y

Jayne, T. S., Chamberlin, J., & Headey, D. D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy, 48*, 1-17. doi:10.1016/j.foodpol.2014.05.014

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80(3), 525-540. doi:10.1016/j.techfore.2012.08.007

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400-411. doi:10.1016/j.landusepol.2014.08.016

Kenya National Bureau of Statistics (KNBS). (2009). Kenya population and housing highlights. Government printer, Nairobi, Kenya.

Kim, D., Thomas, D. A., Pelster, D., Rosenstock, S. T., & Sanz-Cobena, A. (2016). Greenhouse gas emissions from natural ecosystems and agricultural lands in sub-Saharan Africa: synthesis of available data and suggestions for further research. *Biogeosciences* 13, 4789–4809.

KIPPRA (Kenya Institute for Public Policy Research and Analysis). (2017). Kenyan Economic Recovery Report, Popular Version: Sustaining Kenya's Economic Development by Deepening and Expanding Economic Integration in the Region. http://kippra.or.ke/wp-content/uploads/2017/05/KER-2017-Popular-Version-1.pdf, Accessed date: 26 January, 2018.

Lompo, D.J., Sangaré, S.A., Compaoré, E., Sadego, P.M., Predotova, M., Schlecht, E., & Buerkert, A. (2012). Gaseous emissions of nitrogen and carbon from urban vegetable gardens in Bobo-Dioulasso, Burkina Faso. J. Plant Nutr. Soil Sci. 175, 846–853.

Lotze-Campen, H. (2011). Climate change, population growth, and crop production: An overview. In S. S. Yadav, R. J. Redden, J. L. Hatfield, H. Lotze-Campen, & A. E. Hall (Eds.), Crop adaptation to climate change. New Jersey: Wiley

Marenya, P., & Barrett, C. (2009) State-conditional fertilizer yield response on western Kenyan farms. *American Journal of Agricultural Economics*. 91 (4), 991–1006.

Marenya, P. P., & Barrett, C., B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy, 32*(4), 515-536. doi:10.1016/j.foodpol.2006.10.002

Matanda, D. J., Mittelmark, M. B., & Kigaru, D. M. D. (2014). Child undernutrition in Kenya: trend analyses from 1993 to 2008–09. *BMC paediatrics*, *14*1(5): 1-13

Methane, M. K., Smale, M., & Olwande, J. (2014). The impacts of hybrid maize seed on the welfare of farming households in Kenya. *Food Policy, 44*, 262-271. doi:10.1016/j.foodpol.2013.09.013

Muhanji, G., Roothaert, R. L., Webo, C., & Stanley, M. (2011). African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. *International Journal of Agricultural Sustainability, 9*(1), 194-202.

Müller, C., Cramer, W., Hare, W., L., & Lotze-Campen, H. (2011). Climate change risks for African agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 108, 4313–4315.

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117-127. doi:10.1016/j.foodpol.2014.06.010

Ngugi, I. K., Gitau, R., & Nyoro, J. (2007). Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya. *Regoverning Markets Innovative Practice Series, IIED, London.*

Nyamadzawo, G., Shi, Y., Chirinda, N., Olesen, J.R., Mapanda, F., Wuta, M., Wu, W., Meng, F., Oelofse, M., de Neergaard, A. & Smith, J. (2014). Combining organic and inorganic nitrogen fertilization reduces N_2O emissions from cereal crops: a comparative analysis of China and Zimbabwe. *Mitigation and Adaptation Strategies for Global Change*. 1–13.

OECD/FAO. (2016). *OECD-FAO* Agricultural Outlook 2016-2025, OECD Publishing, Paris. http://dx.doi.org/10.1787/agr_outlook-2016-en*,* Accessed date: 25 January 2018

Onium, M., & Mwaninki, P. (2008). Cataloguing and evaluation of available community/farmers-based seed enterprise on African indigenous vegetables for ECA countries. Lagrotech Consultants.

Pelster, D., Rufino, M., Rosenstock, T., Mango, J., Gustavo, Saiz, Eugenio, D., Baldi, G., & Butterbach-Bahl, K. (2017). Smallholder farms in eastern African tropical highlands have low soil greenhouse gas flux. *Biogeoscienc*es. 14, 87–202.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience.* 55 (7), 573–582.

Predotova, M., Gebauer, J., Diogo, R.V., Schlecht, E., & Buerkert, A. (2010). Emissions of ammonia, nitrous oxide and carbon dioxide from urban gardens in Niamey, Niger. *Field Crop Research*. 115, 1–8.

Pretty, J. (1997). The sustainable intensification of agriculture. *Natural Resources Forum* 21(4): 247–256.

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1), 5-24. doi:10.3763/ijas.2010.0583

Rosenstock, T., S., Mathew, M., Pelster, D.E., Butterbach-Bahl, K., Rufino, M., C., Thiong'o, M., Mutuo, P., Abwanda, S., Rioux, J., Kimaro, A. A., & Neufeldt, H. (2016). Greenhouse gas fluxes from agricultural soils of Kenya and Tanzania. *Journal of Geophysical Research: Biogeosciences*. 121, 1568–1580.

Schippers, R. R. (2000). African Indigenous Vegetables, an Overview of Cultivated Species. Natural Institute ACP – EU Technical Centre for Agricultural and Rural Cooperation, Chatham, UK.

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272-284.

Smaling, E. M. A., Stoorvogel, J., & Windmeijer, P. (1993). Calculating soil nutrient balances in Africa at different scales. II: District scale. *Fertilizer Research* 35, 237–250.

Syakila, A., & Kroeze, C. (2011). The global nitrous oxide budget revisited. *Greenhouse Gas Measurement and Management*. 1, 17–26.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labour. *Ecological Economics*, 93, 85-93.

The Montpellier Panel Report. (2013). *Sustainable Intensification*: *A New Paradigm for African Agriculture*, London, UK.

The Royal Society. (2009). Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. RS Policy Document 11/09. The Royal Society, London.

Thornton, P. K., Jones, P. G., Ericksen, P. J., & Challinor, A. J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4 degrees C+ world. *Philosophical Transactions of the Royal Society A,* 369(1934), 117-136. doi:10.1098/rsta.2010.0246

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*. 515 (7528), 518–522.

Tittonell, P., & Giller, K., E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research, 143*, 76-90. doi:10.1016/j.fcr.2012.10.007

Tittonell, P. (2003). Soil fertility gradients in smallholder farms of western Kenya. Their origin, magnitude and importance. Quantitative approaches in system analysis no. 25. The C.T. de Wit Graduate School for Production Ecology & Resource Conservation, in co-operation with the Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), Wageningen, 233 pp., ISBN 90-6754-713-1.

Tittonell, P., Vanlauwe, B., Leffelaar, P., Shepherd, K., & Giller, K. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya –II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture Ecosystems and Environment*. 110, 166–184.

UNDP. (2012). Africa Human Development Report: Towards a Food Secure Future. United Nations Development Programme Regional Bureau for Africa (RBA), New York

United Nations, Department of Economic and Social Affairs, Population Division. (2014). *World Urbanization Prospects: The 2014 Revision, Highlights* (ST/ESA/SER.A/352).

United Nations, Department of Economic and Social Affairs, Population Division. (2015). *World Population Prospects: The 2015 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP.241.

Uusiku, N. P., Oelofse, A., Duodu, K. G., Bester, M. J., & Faber, M. (2010). Nutritional value of leafy vegetables of sub-Saharan Africa and their potential contribution to human health: A review. *Journal of Food Composition and Analysis*, *23*(6), 499-509.

Vanlauwe, B., AbdelGadir, A., Adewopo, J., Adjei-Nsiah, S., Ampadu- Boakye, T., Asare, R., Baijukya, F., Baars, E., Bekunda, M., Coyne, D., Dianda, M., Dontsop-Nguezet, P., Ebanyat, P., Hauser, S., Huising, J., Jalloh, A., Jassogne, L., Kamai, N., Kamara, A., Kanampiu, F., Kehbila, A., Kintche, K., Kreye, C., Larbi, A., Masso, C., Matungulu, P., Mohammed, I., Nabahungu, L., Nielsen, F., Nziguheba, G., Pypers, P., Roobroeck, D., Schut, M., Taulya, G., Thuita, M., Uzokwe, V., van Asten, P., Wairegi, L., Yemefack, M., & Mutsaers, H. (2017). Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa, *International Journal of Agricultural Sustainability*. 15:6, 613-631, DOI: 10.1080/14735903.2017.1393038

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., & Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, 8, 15-22. doi:10.1016/j.cosust.2014.06.001

Vanlauwe, B., Six, J., Sanginga, N., & Adesina, A. (2015). Soil fertility decline at the base of rural poverty in sub-Saharan Africa. Available doi: 10.1038/nplants.2015.101. Accessed 31st January, 2018

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security.

Zingore, S., Murwira, H. K., Delve, R. J., & Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture Ecosystems and Environment* 119, 112–126.

Chapter 2

Drivers of Sustainable Intensification in Kenyan Rural and Peri-urban Vegetable Production

Barnabas K. Kurgat[1*], Evans Ngenoh[2], Hillary K. Bett[2], Silke Stöber[1], Samuel Mwonga[3], Hermann Lotze-Campen [4, 5], Todd S. Rosenstock[6, 7, 8]

1. Centre for Rural Development (SLE), Humboldt-Universität zu Berlin, Hessische Str. 1-2, 10115, Berlin, Germany
2. Department of Agricultural Economics and Agribusiness Management, Egerton University, P.O. Box 536-20115, Egerton, Kenya
3. Department of Crops, Horticulture, and Soils, Egerton University, Kenya, P.O. Box 536 - 20115, Egerton, Kenya
4. Potsdam Institute of Climate Impact Research (PIK), P.O. Box 601203, 14412, Potsdam, Germany
5. Department of Sustainable Land Use and Climate Change, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Germany
6. World Agroforestry Centre (ICRAF), United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
7. CGIAR Research Program on Climate Change, Agriculture, and Food Security, United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
8. World Agroforestry Centre (ICRAF), Avenue des cliniques No 13, c/o INERA, Kinshasa, the Democratic Republic of the Congo

*E-mail of the corresponding author: bkurgat@yahoo.com

Published in International Journal of Agricultural Sustainability, (2018) 16: 4-5, 385-398

Abstract

Sustainable intensification promotes environmentally sound and productive agriculture. However, use of sustainable intensification practices (SIPs) is low in many Sub-Saharan African countries. This study examined the adoption of SIPs in Kenyan rural and peri-urban vegetable production to understand the extent of and underlying factors in the use of SIPs. A multistage sampling technique was employed to randomly select 685 rural and peri-urban vegetable farm households. The data was then collected and analysed for four practices namely improved irrigation, integrated soil fertility, organic manure and crop diversification using a pre-tested structured questionnaire. A multivariate probit model was run to model simultaneous interdependent adoption decisions. The results indicate that adoption of organic manure and African indigenous vegetables *(*AIV) diversification was high in both rural and peri-urban areas. However, adoption of improved irrigation systems and integrated soil fertility management was low, and even significantly lower in rural areas than in peri-urban areas ($p<0.041$). Overall, adoption intensity of SIPs was lower in rural areas than in peri-urban areas. Furthermore, the findings also show complementarities and substitutabilities between SIPs. Market integration, the farm location and household income were the major factors heavily influencing the adoption of most SIPs. Policies and programmes that seek to build household financial capital base and integrate farm households into effective and efficient vegetable markets need to be formulated and implemented in order to enhance sustainable production of AIVs.

Keywords: Adoption, farm households, peri-urban, rural, sustainable intensification, vegetables, Kenya

2.1 Introduction

Agriculture in Sub-Saharan Africa (SSA) needs to dramatically increase food production in response to increased demand and dietary changes as a result of a growing population, increasing urbanisation and rising prosperity (Tilman and Clark 2014). This challenge is complicated by environmental and social constraints, including land and water scarcity, declining soil fertility, climate variability and change (Vanlauwe et al., 2007; The Montpellier Panel, 2013). At the same time, many practices aimed at increasing agricultural productivity degrade the environment such as contributing to global warming and water pollution (Vanlauwe et al., 2011; Kim et al., 2016).

Sustainable intensification (SI), an approach commonly promoted to support environmentally sound agricultural development, aims to produce more food from the existing land base with fewer environmental impacts (Pretty et al., 2011; Godfray, 2015). Farm management practices such as integrated organic and inorganic nutrient management, conservation agriculture (CA), integrated pest management (IPM), crop diversification and sustainable water management (irrigation) have all been suggested as being indicative of sustainable intensification practices (SIPs) (Okalebo et al., 2007; Badgley et al., 2007; Dile et al., 2013). The adoption of such SIPs has been demonstrated to improve yields and nitrogen use efficiency, and conserves resources under certain conditions (Pretty et al., 2011; Teklewold et al., 2013). Despite the practices' potential to provide benefits to farm households and the environment, the adoption of SIPs generally remains low in SSA (Ayaji et al., 2007; Giller et al., 2009; The Montpellier Panel, 2013).

Attempts to understand the determinants of households' decisions to adopt SIPs have been documented in a range of previous studies. Marenya et al. (2007) revealed that household size, the household structure and education level of the household head, the size of farmland owned, the value of livestock and off-farm income significantly influenced smallholder farmers in western Kenya in the adoption of improved natural resource management practices. Kassie et al. (2013) documented several factors, such as environmental constraints (rainfall, insect and disease problems), government effectiveness in the provision of extension services, the size and tenure status of plots, social capital, plot location as well as household assets as influencing farmers' decisions to adopt SIPs, such as minimum tillage, use of animal manure and hybrid maize seeds, in smallholdings in rural Tanzania. Other studies have analysed determinants of adopting SIPs, with household socioeconomic, institutional and environmental factors being the main determinants of SIP adoption (Teklewold et al., 2013; Ndiritu et al., 2014; Kassie et al., 2015).

However, these studies largely focused on farming households cultivating cereal crops (maize) in rural areas of SSA. Only one study has focused on the adoption of safer irrigation technologies (*e.g.* sieving of irrigation water) and crop choices among vegetable farmers in urban Kumasi, Ghana, and found household and farm characteristics such as extension agents, education level of household head, farmers' organisations and cropping patterns to drive use of irrigation (Abdulla et al., 2011). Authors there analysed factors influencing the adoption of safer irrigation technologies only, neglecting the possibility of simultaneously adopting a number of interrelated SIPs. There is no evidence concerning the scale of adoption of interrelated SIPs in smallholder vegetable production systems. Furthermore, there is equally limited information on whether there are any significant differences on the level of adoption of SIPs between rural and peri-urban areas. There may be differences on the scale of adoption of SIPs between these two production environments because farmers in peri-urban areas may have more access to better transport networks, input and output markets, as well as credit and extension services, hence fostering adoption. On the other hand, peri-urban areas are more likely to have better access to off-farm work opportunities with higher wages possibly making it difficult for farmers to adopt labour intensive SIPs, unless they also provide high returns on labour. Therefore, this comparison will provide better understanding on which SIPs are more practiced in rural and peri-urban areas in Kenya. It also helps decision makers and other stakeholders to design specific policies and programs that aim to promote sustainable vegetable production in rural and peri-urban areas while taking into account these potential differences.

Vegetable production, particularly African indigenous vegetables (AIVs), has attracted attention in Kenya's horticultural sector due to the potential offered by AIVs towards improving household food security and income (Ngugi et al., 2007; Abukutsa-Onyango et al., 2010). Furthermore, most of the AIVs have also been reported to have low sensitivity to climate variability and change (Stöber et al., 2017). The growing importance of AIVs to Kenya's food security and smallholder household income is driving AIV intensification both in rural and peri-urban areas. For instance, the area allocated for AIV cultivation in the country has increased by 31%, rising from 27,102 ha in 2009 to 35,503 ha in 2014. In addition, AIV yields and value increased by 6% and 10% respectively between 2012 and 2014 (HCDA, 2014). Despite this increase in land area allocation and yields, AIV supply does not match market demand particularly during dry periods (Muhanji et al., 2011). This is partly due to increasing water scarcity to support year round production of AIVs, declining soil fertility, lack of good quality seeds and knowledge on best agronomic practices, and market barriers (Onium and Manikin, 2008; Muhanji et al., 2011; Croft, et al., 2016), factors that sustainable intensification aim to address. The deficit of AIVs is likely to widen given the projected increase in human population and rising prosperity. It is therefore, important to have a clear understanding on adoption rate of interrelated SIPs and the factors influencing their adoption in order to come up with potential viable options to sustainably intensify AIV production in Kenya. The following SIPs were examined: improved irrigation systems, organic manure, integrated soil fertility and diversification.

This study examined the adoption rate of SIPs and the factors influencing their adoption among smallholder farmers in Kenyan rural and peri-urban AIV production. Specifically, the research asked the following questions: (1) what is the extent of adoption of SIPs in Kenyan rural and peri-urban AIV production? (2), are there differences between rural and peri-urban areas? (3), which factors influence adoption? and (4) which, if any, of the interrelated SIPs complement or substitute one other?

2.2 Methodology

2.2.1 Study site

This study used data from a survey of smallholder farm households conducted in rural and peri-urban regions in Kenya in September-November 2016 by the Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project.

2.2.2 Data collection

Six hundred and eighty-five farming households were selected using a multi-stage sampling technique. In the first stage of the sampling procedure, two production locations were selected based on their AIV production potential: rural and peri-urban. Secondly, two counties were also selected from each production system: Kakamega and Kisii in rural areas and Kiambu and Nakuru from peri-urban areas.

Table 2.1. Sample size and distribution per county and climate characteristics

Region	Counties	Temperature (°C)		Rainfall (mm)	Sample size (n)
		max	min		
Rural	Kakamega	27	14	1,942	197
	Kisii	25	15	2,070	199
Total rural					*396*
Peri-urban	Kiambu	23	12	930	144
	Nakuru	25	11	960	145
Total peri-urban					*289*
Total					685

Thirdly, five to ten divisions were randomly selected from each county depending on the intensity of AIV production and the size of division. Finally, using proportionate to the size sampling approach (according to village household size), farm households were selected at village level and the number of households selected per county is presented in table 2.1. Each household was then given a structured questionnaire to characterise the household socio-economic status and production of AIV, including management practices such as adoption of SIPs (integrated soil fertility management, use of organic manure, improved irrigation systems and AIV diversification) and marketing data. Complementary data on assets, land and livestock ownership, income sources, access to credit and extension services, social networks and farmers' willingness to take production risks (based on farmer perception) were also collected.

2.2.3 Model

A multivariate probit (MVP) model was employed to capture the decision process of farmers in the adoption of multiple SIPs instead of just relying on only a single strategy to optimise their AIV production. Moreover, the model facilitates the understanding of the interconnectedness of different SIPs through the assessment of their respective correlations. Studies that use univariate multinomial logit and probit models do not consider possible correlations of error terms of the adoption equations (Kassie et al., 2013). The weakness of these univariate models is that, they fail to correct for interrelations, which potentially leads to biased estimates (Lin et al., 2005).

A range of factors were considered that would influence farmers' decision to adopt four SIPs (improved irrigation, integrated soil fertility management, organic manure and AIV diversification). To describe the MVP model, let SIP_i denote a random variable taking on the values (1, 2, 3, 4) for a positive integer, in this case representing all the four SIPs, and let X denote a set of conditioning variables. Therefore, the SIPs chosen by any AIV farming household were represented by random variables (SIP_i). It was assumed that each farmer may consider a combination of SIPs, which was further assumed to depend on a set of the households' socio-economic, demographic and institutional characteristics as well as other factors (X). Therefore, the MVP model for this study was characterised by a set of binary dependent variables (SIP_{ipn}) such that:

$$SIP_{ipn}^{*} = \beta_n' X_{ipn} + u_{ipn}\,, \qquad n = 1, \ldots.., N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.1)$$

and

$$SIP_{ipn} = \begin{cases} 1\ if\ SIP_{ipn}^{*} > 0 \\ 0\ otherwise \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

where, β_n' is the corresponding vector of parameters to be estimated and SIP_{ipn}^{*} is the latent variable. Equation (2.1) assumes that a rational AIV smallholder farming household has a latent variable, SIP_{ipn}^{*}, that captures the unobserved preferences associated with the n^{th} choice of SIPs. This latent variable was assumed in this study to be a linear combination of both household socioeconomic and institutional characteristics (X_{ipn}) that are observed to be influencing the simultaneous selection of SIPs, as well as the unobserved characteristics that are captured by the stochastic error termu_{ipn}. Owing to the nature of the latent variable, the estimations in this study were based on observable binary discrete variables SIP_{ipn}, which indicate whether or not an AIV farming household has selected a particular SIP.

2.2.4 Descriptive statistics of variables

The definition and descriptive statistics of variables used in the analysis are presented in table 2.2.

2.2.4.1 Dependent variables

One of the SIPs considered was the use of improved irrigation systems, described here as the use of hosepipe-sprinklers fitted with electric-motorized pumps to pump water from wells/rivers and take it to vegetable fields. This irrigation system conserves water and is less labour intensive than the use of watering cans. Manual irrigation with watering cans is time consuming. Danson et al. (2002) noted that manual irrigation takes 13% of the total cost (excluding family labour) or 38% of a farmer's time, and high water application rates (640-1,600 mm yr^{-1}) in year-round irrigation of peri-urban vegetable production in Ghana. Additionally, the weight of water (10 -15 litres per can) limits its use to fields close to water sources (Drechsel et al., 2006). Therefore, the use of improved irrigation systems conserves water and reduces production costs hence increases livelihoods gains (crop income). It is therefore assumed that adoption of improved irrigation systems has high probability of improving sustainability of AIV production.

Integrated soil fertility management is a soil management approach that emphasize combine use of organic and mineral fertiliser inputs with the goal of improving yields and fertiliser use efficiency (Vanlauwe et al., 2014; Pincus et al., 2016). Chivenge et al. (2010) indicate from a meta -analysis of studies across SSA that, combined use of organic and mineral fertiliser input leads to greater yield response than either input on its own. In addition, Kurgat et al. (2018) established that mixing animal manure with inorganic fertilizers efficiently and effectively optimizes livelihoods gains with minimal negative environmental impacts (less nitrous emissions) based on on-farm trials carried out in African nightshade cultivation fields in peri-urban areas in Kenya. Applying organic manure from livestock waste to croplands potentially returns organic matter to the soil which in turn leads to increased soil quality and soil biota, improves soil water-holding capacity and increases the potential of soil to sequester carbon (The Montpellier Panel Report, 2013). Crop biodiversity is considered a cornerstone of long-term food security because it provides a wider range of genetic raw material that enables food crops to adapt to ever-changing environmental conditions, including emerging pathogens, evolving pests and climate change. AIV diversification – denoted by the number of AIVs grown by the farming household – was included in this study as an indicator of sustainable intensification (SI) of AIV production.

2.2.4.2 Explanatory variables and hypotheses

Several previous studies on farm technology adoption have supported the use of empirical models to determine factors influencing adoption or non-adoption (Shiferaw et al., 2007; Kassie et al., 2013; Teklewold et al., 2013; Kassie 2015). The following section therefore, contains a discussion about the explanatory variables that were selected as determining factors in decision-making and whether these variables have a positive, negative or inconsistent influence on the adoption of SIPs in AIV production.

a) Household characteristics

Household characteristics were built into the model, controlling for household size, age, level of education and the household structure (household head being male or female). These four socio-demographic variables have also been used in previous studies to define decision-making in the adoption of farm technologies (Asfaw et al., 2014; Kassie et al., 2010). In terms of education, it is assumed that better educated farmers are more likely to receive off-farm income, which enables them to invest in new technologies and purchase, inputs and have better analysis regarding benefits of new technologies in solving farm production constraints. Conversely, better-educated farmers may be less willing to invest in labour-intensive technologies and would rather opt for off-farm jobs offering better returns on labour (Lee, 2005; Shiferaw et al., 2007). Half (50.8%) of the sampled households received 8.4 years of education on average, implying that the maximum education attained was primary level based on Kenyan education system.

From this study, the age of the household head ranged from 20-91 years, with a mean average age of 52.7 years. Concerning household structure, the data revealed that the majority (82%) of the sampled households were headed by men. Older farmers were likely to have been exposed to a wider range of production technologies and environments, accumulated more wealth, and built larger social networks, and hence there is a better chance of them adopting SIPs. However, old age is also associated with a loss of energy, risk aversion and short-term investment planning (Kassie et al., 2013; Asfaw et al., 2014). Women are often excluded from access to land, livestock and other assets, as well as markets and extension services due to the social and cultural perceptions of the role of women in African societies (Ndiritu et al., 2014).

Table 2.2. Description and summary statistics of variables used in multivariate probit model

Dependent variables	Description of the variables	Mean	Std. Dev
Improved irrigation system	Farmers using improved irrigation (1=yes; 0=no)	0.12	0.33
Organic manure	Farmers using organic manure (1=yes; 0=no)	0.66	0.48
Integrated soil fertility management	Households using both animal manure and inorganic fertilisers (1=yes; 0=no)	0.09	0.29
AIV diversification	Farmers growing more than one AIV on their farm (1=yes; 0=no)	0.83	0.38
Explanatory variables		Mean	Std. Dev
Household characteristics			
Household size	Total household/family size (numbers)	6.11	2.37
Household head is male	Household structure (1=male; 0=female)	0.82	0.39
Age of household head	Age of the household head in years	52.70	12.64
Education level	Education level of the household head (years of schooling)	8.47	4.66
Willingness to take risk†	Household head willingness to take risk (1=yes; 0=no)	0.76	0.43
Asset endowment			
Natural logarithm of land size	Natural logarithm of household land size (acres)	0.28	1.07
Farming as main occupation	Household head with farming as main occupation (1=yes; 0=no)	0.62	0.49
Livestock ownership	Household owning livestock (1=yes; 0=no)	0.97	0.16
Farm ownership	Household land ownership (1=owned; 0=otherwise)	0.96	0.19
Natural logarithm total income	Natural logarithm of total household income (KShs)	9.43	0.79
Land fertility	Household land fertility (1=Fertile; 0=otherwise)	0.37	0.50
Market access			
Informal market integration	Household selling any of AIVs grown (1=yes; 0=no)	0.69	0.46
Formal market integration	Household participating in the formal market (1=yes; 0=no)	0.30	0.46
Natural logarithm of distance to market	Natural logarithm of distance to the nearest market (km)	0.63	0.70
Institutional factors			
Extension	Household accessing extension services (1=yes; 0=no)	0.64	0.48
Access to credit	Household accessing credit services (1=yes; 0=no)	0.24	0.42
Group membership	Household member belong to AIV farmer group (1=yes; 0=no)	0.37	0.48

Table 2.2. Continued

Dependent variables	Description of the variables	Mean	Std Dev
Information on new agricultural technologies	Household access to information on new agricultural technologies and innovations (1=yes; 0=no)	0.38	0.49
Information on health benefits of AIVs	Household having information on health benefits of AIVs (1=yes; 0=no)	0.72	0.45
Environmental constraints			
Crop pest	Households who faced crop pest attack (1=yes; 0=no)	0.07	0.25
Crop disease	Households who faced crop disease attack (1=yes; 0=no)	0.05	0.21
Water shortage	Water shortage during the growing season (1=yes; 0=no)	0.08	0.27
Unusual heavy rainfall	Unusually heavy rainfall in the growing season (1=yes; 0=no)	0.13	0.34
Drought	Households who faced drought events (1=yes; 0=no)	0.40	0.49
Farm location			
Peri-urban	Household is located in peri-urban area (1=yes; 0=no)	0.42	0.50

Note: † denotes farmer’s willingness to take production risk based on their perceptions

Therefore, the education level and age of household head have a countervailing effect on the adoption rates of SIPs. Household size is one proxy indicator for the availability of family labour. The average household size of the sampled households varied from 1 to 15 household member (s), with an average household size of 6 members. As some of SIPs are quite labour intensive, household size can positively influence their adoption (Lee, 2005).

b) Household asset endowment

Land size, total household income, land and livestock ownership were used to represent household asset (wealth) endowment. Households with a strong capital base are likely to invest in capital-intensive technologies and finance the purchase of inputs, such as chemical fertilisers. Households that lease land (tenants) are risk averse and are not likely to invest in capital-intensive SIPs as they might feel threatened by contract termination and eviction. Livestock provides manure as a side product that could be used in crop production (Kassie et al., 2013). However, livestock also competes for other resources such as water and family labour, and may negatively affect the adoption of certain SIPs. Households with more land may feel less need to intensify their production compared to households with less land. In the sample, agricultural land is generally small, with 96% of the respondents owning land, which was on average size 0.28 acres. Of the farmers surveyed, 62% were full-time farmers and almost all (97%) owned at least one or more livestock.

c) Market access

In general, market imperfections such as structural constraints, failure to pay on delivery or lack of understanding of price differentiation in different market outlets limit the attractiveness of adopting and investing in SIPs (Lee 2005, Chelang'a et al., 2013). Farmers participating in market outlets and selling their farm products are likely to achieve better economic returns from their investments. Croft et al. (2016) reported that AIV famers selling their vegetables to formal markets[7] had a higher gross income than those supplying to informal markets[8]. This, in turn, may increase their likelihood to invest in SIPs. A dummy variable equal to one (and zero otherwise) was included if the household sold any of the AIVs produced. From the data, 69% of the households also produced AIVs for selling, and 31% were pure subsistence farmers. Another dummy variable was included if the household sold any AIV

[7] Markets with formalized transaction systems and also with clear market institutions such as supermarkets, retail groceries, institutions and hotels.

[8] Informal market are either undesignated areas near farming communities or in peri-urban areas where door-to-door and roadside markets do exist and suppliers and buyers exists with very few or no transaction documents.

produce directly to any formal market. The survey shows 30% of farmers sold to supermarkets, hotels, restaurants or schools, and were therefore considered as being integrated into the formal market. The remaining 39% of farmers sold their AIV produce to informal markets, such as brokers or middlemen, roadside kiosks or open market stalls. It was assumed that market integration in general, and formal market participation in particular, has a positive impact on the adoption of SIPs. Distance to market is another influencing factor in the adoption of SIPs because increasing distance means a rise in transaction costs due to reduced access to market information and inputs (Mbaga-Semgalawe and Folmer, 2000). Gotor and Irungu (2010) reveal that market information on AIVs decreases with increasing distance from Nairobi. Similar to this finding, this study expects market distance to have a negative impact on the adoption of SIPs.

d) Institutional variables

Social capital emerges through bonding or bridging networks and has been denoted as an important determining factor in the diffusion of innovation as well as adoption theory and practices (Rogers, 2003). Social capital facilitates the exchange of information and enables farmers to access inputs and overcome credit constraints, particularly in areas where information sources are scarce or inadequate and there are imperfect markets with high transaction costs (Kassie et al., 2013). In this study, the households' social capital was operationalised as the household's membership of a producer and/or marketing group. In the present sample, 37% of the AIV producers were members of a group. It was assumed that being a member of a producer or a marketing group positively influenced the adoption rate of SIPs.

e) Environmental constraints

Even though AIVs have been reported to tolerate a wide spectrum of weather variability, some AIV species are rather sensitive to pest and diseases as well as weather-related shocks such as dry spells or water logging caused by too little or too much rainfall (Stöber et al., 2017). Furthermore, Shackleton et al. (2009) observed that AIVs can be harvested more than once per season. This intensive production requires good soil fertility management to sustainably maintain the crop productivity. Therefore, a dummy was used to estimate the soil fertility of AIV plots based on farmers' perceptions of land or plot fertility. It was assumed that the level of plot fertility had negative or positive impact on the SIP adoption rate. A set of dummies equal to one was included for various problems faced by the farming household, specifically AIVs infected by pests and diseases, water shortages, and the incidence of extreme weather events such as unusual heavy rainfall or dry spells in the growing season. It was assumed that pests and diseases, water shortages and exposure to weather-related shocks had a positive impact on the adoption rate of SIPs.

f) Farm location

AIVs are highly perishable leafy vegetables that require a properly maintained cool supply chain to increase their shelf life. Cooling facilities, appropriate infrastructure and easy market access depends on proximity to the market. Therefore, AIVs produced in peri-urban areas are likely to reach the market fresher than those produced in rural areas (Weinberger and Pichop, 2009). Formal markets, such as supermarkets, demand high quality standards (for example, leaf size and appearance of freshness). AIV famers producing AIVs in peri-urban areas are more likely to penetrate these formal markets, fetching higher economic returns compared to AIV producers in rural areas. For instance, Indeche et al. (2017) found that AIV farmers in remote rural Kakamega lack knowledge on quality standards, especially with regard to the transaction costs attributed to formal market integration. Therefore, a dummy variable equal to one was included if the household produced AIVs in a peri-urban region (Kiambu, Nakuru), where 42% of the households were located, and zero for the remaining 58% residing in rural areas (Kakamega, Kisii). It was assumed that the per-urban production environment positively influences adoption of SIPs.

2.3 Results and discussion

2.3.1 Level of adoption

The level of adoption of SIPs varied considerably between practices and locations. The most widespread SIP was AIV diversification, with 83% of the households planting more than one AIV species. Diversification of AIV species was significantly ($p<0.03$) more widespread in rural areas than in peri-urban areas. The application of organic manure was also a widely disseminated practice, with 66% of the farmers using organic (animal) manure on their AIV plots. This is fairly similar to the mean adoption level of 70% of using animal manure documented for smallholder farmers cultivating maize in Kenya, but 30% less than the adoption levels for the same crop cultivated in Malawi, Ethiopia and Tanzania (Kassie et al., 2015). Furthermore, the present findings were slightly higher compared to the adoption level of manure application of approximately 50% reported by smallholder farmers cultivating maize in rural western Kenya (Marenya et al., 2007). On average, this suggests a slightly higher adoption of organic manure in vegetable production compared to staple crops such as maize in SSA. Only a very small proportion of farming households used improved irrigation systems and integrated soil nutrient management, with an adoption level of 12% and 9% respectively. This low adoption levels of these two SIPs was even significantly lower in rural areas than in peri-urban areas (Table 2.3).

Table 2.3. Adoption levels as the share of the total number of households and per farm location

Type of SIPs	Share from total N		Production system (%)		
	No of households	%	Peri-urban	Rural	Chi2(p-value)
Improved irrigation systems	85	12.4	90.6	9.4	93.20****
Organic manure	451	65.8	44.3	55.7	2.52
Integrated soil fertility management	62	9.1	59.7	40.3	8.55**
AIV diversification	566	82.6	40.1	59.9	5.80**

****and ** indicate significance at $p < 0.001$ and 0.05 respectively

These findings imply that while many farmers use and might be benefiting from ecological benefits of organic manure, a larger proportion of them do not gain economic and environmental outcomes of using improved irrigation systems and integrated soil fertility management. There is a need, therefore, for stakeholders working on programs that seeks to improve sustainable production of AIV to focus more on how to improve uptake of these two SIPs.

2.3.2 Adoption intensities

Adoption intensity, defined here as the number of SIPs practised by the AIV producer, ranged from zero to four. Overall, the adopters of two SIPs were highest both in rural and peri-urban areas compared to adopters of one or three SIPs. 62% and 38% of farmers adopted two SIPs in rural and peri-urban areas respectively. Adopters of one or two SIPs were slightly more widespread in rural areas, with 65% compared to 35% peri-urban adopters.

However, the proportion of adopters practising three SIPs was higher in peri-urban areas (92%) compared to 7% in rural areas (Figure 2.1). None of the farmers in the rural areas adopted the highest intensity of four SIPs, and only one peri-urban farmer did so. These results indicate a slightly higher adoption intensity in peri-urban settings compared to rural areas. This suggests that AIV production in peri-urban areas is probably done using SIPs compared to rural areas in Kenya. This might be attributed to better market integration, more information about SIPs, and greater access to market prices and farm inputs in peri-urban areas that offer farm households higher economic returns from their investments, resulting in them being motivated to invest in more SIPs.

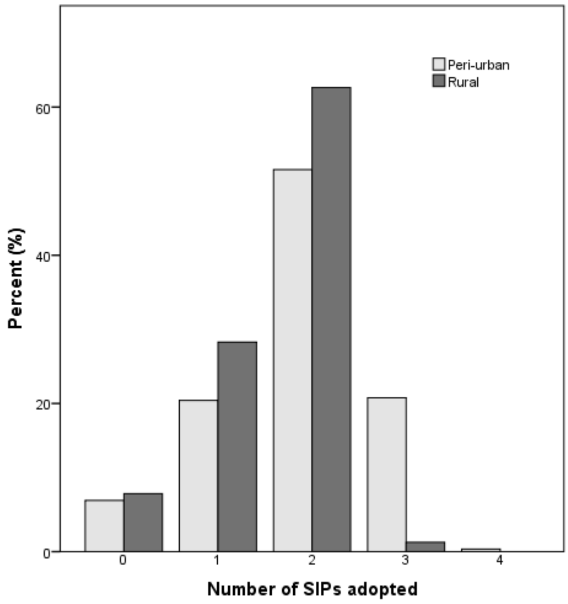

Figure 2.1. Percentage of farming households from rural and peri-urban areas who practiced either 1, 2, 3 or all the 4 sustainable agricultural practices.

2.3.3 Complementarities and substitutabilities

The alternative hypothesis of mutual interdependence among SIPs was statistically significant (likelihood ratio test (chi^2 (6)) = 163.609, p< 0.000). This supports the choice of the multivariate probit model in this adoption study. Additionally, four out of six coefficients of pairwise correlation were significantly correlated, demonstrating that some SIPs complement or substitute one other (Table 2.4). For instance, improved irrigation systems and integrated soil fertility management were positively correlated, as were use of organic manure and AIV diversification. The relationship between integrated soil fertility management and use of organic manure was negative, as was that between integrated soil fertility management and AIV diversification. One possible reason for this could be that households usually decide on just one distinct soil fertilisation method. Moreover, if households have insufficient resources they potentially opt for organic manure because integrated soil fertility management is labour intensive and costly due to necessity of buying fertiliser.

2.3.4 Drivers and barriers of adoption of SIPs

The six categories of explanatory variables had different influence on the adoption and non-adoption of SIPs (Table 2.5). With regard to household characteristics, male-headed households with fewer members were more likely to adopt improved irrigation systems. This may be attributed to resource endowment characteristics and the higher labour availability of male-headed households. For instance Mulwa et al. (2017) found that the availability of male family labour conditioned the adoption of soil and water conservation measures in Malawi. However, large households are likely to spend most of their income on food and other basic needs. This in turn reduces the household's ability to invest in improved irrigation systems, which are usually capital intensive. The education level of the household head however was an important factor determining the adoption of organic manure.

Table 2.4. Correlation coefficients of adoption of SIPs from MPV model

	$\rho_{improved\ irrigation\ system}$	$\rho_{organic\ manure}$	$\rho_{integrated\ soil\ fertility\ management}$
$\rho_{organic\ manure}$	-0.117(0.081)		
$\rho_{integrated\ soil\ fertility\ management}$	0.374(0.094)****	-0.854(0.046)****	
$\rho_{AIV\ diversification}$	0.128(0.095)	0.326(0.068)****	-0.151(0.083)*

Likelihood ratio test of: $\rho_{organic\ manure} = \rho_{improved\ irrigation\ system} = \rho_{integrated\ soil\ fertility\ management} = \rho_{improved\ irrigation\ system} = \rho_{AIV\ diversification} = \rho_{improved\ irrigation\ system} = \rho_{integrated\ soil\ fertility\ management} = \rho_{organic\ manure} = \rho_{AIV\ diversification} = \rho_{organic\ manure} = \rho_{AIV\ diversification} = \rho_{integrated\ soil\ fertility\ management} = 0$; $X^2(6)= 163.23$****

****and * indicate significance at p<0.001 and 0.1 respectively

This result is consistent with the results of Waithaka et al. (2007) and Gel go et al. (2016), who reported a similar positive relationship between the education level of the household head and adoption of organic manure among smallholder farmers in western Kenya and in Shashemene district in Ethiopia. This implies that more public and private investment on farmer training and education programs are potential pathways to increase use of organic manure as well as achieve sustainable AIV production in Kenya.

Farmers' willingness to take production risks significantly affected the adoption of integrated soil fertility management as a means of SIP. This may imply that farmers consider investment in integrated soil fertility management a risky endeavour, perhaps due to higher investment costs and greater expected returns. Therefore, risk-taking farmers are likely to opt for integrated soil fertility management and expect higher economic returns. For organic manure it is the opposite since risk-takers do not adopt soil fertility management based on the use of organic fertilisers. Those claiming that their main occupation is full-time farming were more likely to adopt improved irrigation systems. They rely on income from farming to support their livelihoods, and therefore avoid the risk associated with rain-fed dependency or the workload of traditional irrigation systems for AIV production. Improved irrigation systems are less labour and water intensive and guarantee household income even in dry seasons. Land ownership conditioned the adoption of organic manure, which is consistent with previous studies by Kassie et al. (2013) and Asfaw et al. (2014). They reported a similar positive relationship between land ownership and adoption of manure among smallholder farmers in Tanzania and Malawi. Land ownership is associated with greater tenure security, which increases farmers' likelihood of adopting strategies that will capture the returns on their investment in the long run.

Livestock ownership negatively affected adoption of improved irrigation systems on AIV plots. Livestock compete with irrigation for water and labour. Furthermore, keeping livestock for milk production is a major enterprise for most smallholder households in Kenya and is often associated with higher economic returns. In this study area, farmers specialised in livestock production (allocating more household resources) instead of intensifying vegetable production through improved irrigation systems.

Household income significantly ($p<0.0001$) determined the adoption of improved irrigation systems, use of organic manure and AIV diversification. This is consistent with the wider view that when access to credit is limited, better-off households are doubly advantaged by having more resources to invest in SIPs and at the same time enough liquidity to invest in SIPs that require cash payments upfront (Pender and Kerr, 1998). This shows the essence of cash in the early stages of adoption decisions, *i.e.* cash is needed to purchase irrigation equipment (motorized-motor pumps and pipes), drill boreholes or wells, and pay for labour. The positive relationship between income and adoption of organic manure contradicts the findings of Waithaka et al. (2007) who reported an inverse relationship between increase in income and use of organic manure among smallholder farmers in western Kenya. This may be due to the fact that manure in rural western Kenya is not income dependent because most farmers keep their own livestock and the manure market is almost inexistent. However, in this study, particularly in peri-urban areas, organic manure is an external input bought from other counties.

Table 2.5. Parameter estimates from MVP model for estimating determinants of adoption of SIPs (standard errors in parenthesis)

Explanatory variables	Dependent variables			
	Improved irrigation system	Organic manure	Integrated soil fertility management	AIV diversification
Household characteristics				
Household size	-0.090(0.042)**	-0.000(0.024)	0.004(0.034)	0.018(0.029)
Household head is male	0.372(0.225)*	-0.003(0.141)	0.134(0.185)	0.077(0.160)
Age of household head	0.010(0.006)	-0.001 (0.004)	-0.004 (0.005)	0.006(0.005)
Education level	0.023(0.018)	0.022(0.011)*	0.001(0.014)	-0.016(0.013)
Willingness to take risk	0.263(0.204)	-0.175(0.125)	0.437(0.198)***	-0.012(0.144)
Asset endowment				
Natural logarithm of land size	-0.120(0.079)	-0.046(0.053)	-0.086(0.072)	-0.017(0.060)
Farming as main occupation	0.347(0.018)*	0.083(0.113)	-0.169(0.150)	-0.013(0.132)
Livestock ownership	-0.849(0.388)**	0.085(0.306)	0.098(0.401)	-0.217(0.379)
Farm ownership	-0.177(0.424)	1.047(0.280)****	0.289(0.472)	-0.312(0.326)
Natural logarithm total income	0.285(0.115)**	0.221(0.074)***	-0.290(0.096)***	0.260(0.085)***
Land fertility	0.189(0.164)	-0.059(0.108)	-0.128(0.141)	0.112(0.130)
Market access				
Informal market integration	1.303(0.277)****	0.264(0.131)***	0.269(0.195)	0.857(0.153)****
Formal market integration	0.034(0.182)	-0.217(0.131)*	0.317(0.158)**	-0.164(0.169)
Natural logarithm of distance to market	0.229(0.082)***	-0.032(0.061)	-0.037(0.078)	0.056(0.078)
Institutional factors				
Extension	0.183(0.180)	0.016(0.122)	0.052(0.166)	0.165(0.145)
Access to credit	-0.228(0.197)	-0.061(0.125)	-0.178(0.163)	-0.112(0.149)
Group membership	-0.120(0.211)	0.217(0.124)*	0.055(0.161)	0.148(0.153)
Information on new agricultural technologies	0.198(0.187)	-0.193(0.121)	0.388(0.172)**	-0.047(0.144)
Information on health benefits of AIVs	0.152(0.218)	-0.240(0.141)*	-0.145(0.191)	-0.164(0.168)

Table 2.5. Continued

Explanatory variables	Dependent variables			
	Improved irrigation system	Organic manure	Integrated soil fertility management	AIV diversification
Environmental constraints				
Crop pest	0.208(0.257)	-0.002(0.205)	-0.111(0.261)	-0.380(0.219)*
Crop disease	0.396(0.346)	-0.135(0.245)	0.235(0.299)	0.486(0.377)
Water shortage	-0.180(0.332)	0.343(0.206)*	-0.276(0.290)	-0.406(0.212)*
Unusual heavy rainfall	0.108(0.235)	-0.111(0.153)	0.332(0.184)*	-0.008(0.184)
Drought	0.062(0.183)	-0.134(0.112)	0.115(0.152)	-0.150(0.134)
Farm location				
Peri-urban	1.364(0.235)****	-0.163(0.132)	0.416(0.181)**	-0.226(0.149)
Constant	-6.377(1.382)****	-2.85(0.827)***	0.186(1.197)	-2.287(0.960)**
Regression diagnostics for MVP model				
Number of observations		685		
Log pseudo-likelihood		-950.073		
Wald Chi2 (100)		269.80****		

****, ***, ** and * indicate significance at p<0.001, 0.01, 0.05 and 0.1 respectively.

Integrated soil fertility management is negatively correlated with household income. This may be due to the high share of off-farm and non-farm income in households with a higher income, and part-time farmers being less interested in investing in integrated soil fertility as the farm is not the primary source of livelihood. Farmers with a higher household income may prefer to invest their time, energy and cash in more risky enterprises that will earn them greater economic benefits than investing in labour intensive integrated soil fertilisation.

Market integration had a strong influence on the adoption of SIPs. The 69% of farmers who sell AIVs to informal markets significantly adopted improved irrigation systems, use of organic manure and diversifying AIV production. Those selling AIVs through formal market outlets were also more likely to adopt integrated soil fertility management, but refrained from solely using manure. These findings suggest that integrating farmers with formal or informal AIV market outlets encourages the uptake of SIPs since the adoption may have economically rewarding effects for farmers.

The positive relationship between market participation and AIV diversification, however, contradicted the common assumption that market linkages contribute to the loss of agro-biodiversity. For instance, Ngugi et al. (2007) reveal that the AIV market demand in Nairobi and the surrounding areas is limited to a few species, and therefore negatively affects the opportunities for farmers to diversify in AIVs for sale. The inverse relationship between formal market integration and use of manure could be due the fact that market-integrated farm households use fertilisers because they are likely to have more money to purchase it. The significant ($p<0.0004$) positive relationship between distance to the nearest market and adoption of improved irrigation systems was not expected. One possible reason for this could be the high demand for AIV throughout the year, particular during the dry season, and the possibility of selling it directly to the consumer or retailer a short distance away.

Access to farmers' groups and information on new agricultural technologies and innovations significantly determined adoption of organic manure and integrated soil fertility management. Ayaji et al. (2007) revealed similar findings that farmers organised in groups were more likely to apply organic manure in Cameroon. The positive influence of farmers' groups on the adoption of integrated soil fertility management was consistent with the common understanding of social networks facilitating access to information, knowledge and credit, thereby considerably reducing transaction costs. Group marketing leads to greater bargaining power, which in turn enhances the adoption of new technologies (Bandiera and Rasul, 2006). This finding suggests that social networks would be effective entry points for enhancing farmers' capacity to adopt SIPs, also recommended in the adoption of SI for climate change adaptation (Vignola et al., 2015).

Environmental constraints had a mixed effect on the adoption of SIPs. For example, it seemed that AIV farmers understood the positive effect of organic manure in conserving soil moisture content, as water shortage positively affected the adoption of organic manure. Similar results are reported by Gandure et al. (2013), with water shortage and evaporation losses being the main contributors to the adoption of mulching. Unusually heavy rainfall also had a positive impact on the adoption of integrated soil fertility management. Incidences of crop pest attacks and water shortages meanwhile negatively affected the adoption of AIV diversification. This result was in contrast to the general understanding that crop diversification is a strategy employed by farmers to reduce production risks associated with pest and disease attacks, and harsh weather (Teklewold et al., 2013). This could mean that farmers who face water shortages and pest attacks are likely to opt for other staple crops rather than cultivate more AIVs.

With regard to the level of farm location, the coefficient for AIV production in peri-urban areas was positive and significant ($p<0.0006$) in the adoption of improved irrigation systems and integrated soil fertility management. Peri-urban areas are characterised by improved infrastructural development – transport and communications – ,which enables farmers to access farm inputs and technologies, lucrative urban market outlets and relevant information at reduced transaction costs than their counterparts in rural areas.

2.4 Conclusion

This study is one of the first to examine the scale of and factors influencing the adoption of interrelated SIPs among rural and peri-urban smallholder farmers in Kenya producing AIVs. The findings revealed that use of organic manure and AIV diversification was widespread, both in rural and peri-urban vegetable production, and in general higher than other field crops such as maize. However, the adoption of improved irrigation systems and integrated soil fertility management was rather low and even significantly lower in rural areas compared to peri-urban settings. Similarly, the adoption intensity of multiple SIPs was less prevalent in rural areas than in peri-urban areas. This finding suggests that specific targeted approaches are needed to increase the adoption of improved irrigation systems and integrated soil fertility management in the two areas. Such promotion programmes should be emphasised more in rural areas through local institutions such as farmers' groups, as social capital is a major determinant of adoption of SIP.

The study also revealed complementarities and substitutabilities between SIPs, implying that policy changes that affect adoption of a given SIP may also influence adoption of other SIPs. Therefore, when a set of SIPs complement one other, farmers should be encouraged to adopt such SI packages. Adopting a range of SIPs would contribute more effectively to the desired productivity and environmental protection compared to a single SIP that might only solve one issue, *e.g.* irrigation for dry season production. Household characteristics, household income, market integration, level of urbanisation, environmental constraints and institutional factors influenced the decision to adopt SIPs in a heterogeneous way. These findings imply that the SI of AIVs could potentially be promoted through well-designed policies and programmes targeting the integration of farm households in effective and efficient vegetable markets, build household financial capital base, and improve land tenure security. Furthermore, social capital and farmers' groups play a crucial role in the choice of adoption. Farmers' institutions may be an efficient channel for promoting the adoption of SIPs, particularly those with low adoption levels, as wells as other agricultural technologies not yet included here. Future studies may be necessary to build up evidence on the relative economic and environmental advantages and complexity of SIPs in vegetable production in order to develop guidelines for SIPs in leafy vegetables and AIVs. It is also important to evaluate whether there is any gender difference with regard to adoption of SIPs in vegetable production in peri-urban and rural areas.

Acknowledgments

This study is part of the Horticultural Innovations and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project funded by the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry of Economic Cooperation and Development (BMZ) within the framework of the GlobE – Global Food Security programme (Ref : FKZ 031A248A). The authors are equally grateful to the farm households for allowing us to interview them. Equally, we are thankful to Egerton University for their support in organising the logistics for the survey.

References

Abdulla, A., Owes, V., & Baking, J. A. (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, 70(7), 1415-1423. doi:10.1016/j.ecolecon.2011.03.004

Abukutsa-Onyango M. K., P., Amoke, P., & Habwe, F. (2010). Iron and Protein Content of Priority African Indigenous Vegetables in the Lake Victoria *Basin. Journal of Agricultural Science and Technology, 4*(29), 67-68.

Ajayi, O. C., Akinnifesi, F.K., Sileshi, G., & Chakeredza, S. (2007). Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. *Natural Resources Forum*, 31, 306–317.

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2014). Climate variability, adaptation strategies and food security in Malawi. ESA Working Paper No. 14-08. Rome, FAO.

Badgley, C., Mightier, J., Quintero, E., Zaeem, E., Chappell, M. J., Aviles-Vázquez, K., Samul on, A., & Perfecto, I. (2007). Organic agriculture and the global food supply. *Agriculture and Food Systems* 22 (2), 86–108. oi:http://dx.doi.org/10.1017/S1742170507001640.

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in Northern Mozambique. *The Economic Journal,* 116, 869–902.

Chelang'a, P. K., Obare, G. A., & Kimenju, S. C. (2013). Analysis of urban consumers' willingness to pay a premium for African Leafy Vegetables (ALVs) in Kenya: a case of Eldoret Town. *Food Security*, *5*(4), 591-595.

Chivenge, P., Vanlauwe, B., Six, J., 2010. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. Plant Soil 342, 1–30. doi:http://dx.doi.org/10.1007/s11104-010-0626-5.

Croft, M. M., Marshall, M.I., & Hallett, G. S. (2016). Market Barriers Faced by Formal and Informal Vendors of African Leafy Vegetables in Western Kenya. *Journal of Food Distribution Research, 47*(3), 49-60.

Danson, G., Drechsel, P., Wiafe-Antwi, T., & Gyiele, L. (2002). Income of farming systems around Kumasi, Ghana. *Urban Agriculture Magazine*, 7:5-6.

Dile, Y. T., Karlberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agriculture, Ecosystems & Environment*, 181, 69-79. doi:10.1016/j.agee.2013.09.014

Drechsel, P., Graefe, S., Sonou, M., & Cofie, O. (2006). *Informal irrigation in urban West Africa: An overview*. Colombo, Sri Lanka, International Water Management Institute. (IWMI Research Report 102).

Gandure, S., Walker, S., & Botha, J. J. (2013). Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. *Environmental Development*, 5, 39-53. doi:http://dx.doi.org/10.1016/j.envdev.2012.11.004

Gel go, B., Mshenga, P., & Zemedu, L. (2016). Analysing the Determinants of Adoption of Organic Fertilizer by Smallholder Farmers in Shashemene District, Ethiopia. *Journal of Natural Sciences Research*, 6(19), 35-44.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23-34. doi:10.1016/j.fcr.2009.06.017

Godfray, J. C. (2015). The debate over sustainable intensification. *Food Security*, 7, 199-208.

Gotor, E. & Irungu, C. (2010). The impact of Biodiversity international's African leafy vegetable programme in Kenya. *Impact assessment and project appraisal*, 28(1) pp. 41-55.

HCDA. (2014). *National horticulture validated report*. Kenya, Ministry of Agriculture, Department of Horticultural Crops Development Authority. Kenyan Government printer. Retrieved from http://www.agricultureauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf

Indeche, A., Mensah A. O., & Annor-Frempong, F. (2017). Level of Knowledge on Quality Standards of High Value Markets in Kenya among Indigenous Vegetable Women Farmers in Kakamega County. *International Journal of Contemporary Applied Sciences*, 4(3), 26-34.

Kassie, M., Zikhali, P., Pender, J., & Köhlin, G. (2010). The economics of sustainable land management practices in the Ethiopian highlands, *Journal of Agricultural Economics*, 61 (3) 605–627.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80(3), 525-540. doi:10.1016/j.techfore.2012.08.007

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400-411. doi:10.1016/j.landusepol.2014.08.016

Kim, D., Thomas, D.A., Pelster, D., Rosenstock, S.T. & Sanz-Cobena, A. (2016). Greenhouse gas emissions from natural ecosystems and agricultural lands in sub-Saharan Africa: synthesis of available data and suggestions for further research. *Biogeoscience*s 13, 4789–4809.

Kurgat, B.K., Stöber, S., Mwonga, S., Lotze-Campen, H., Rosenstock, S. (2018). Livelihood and climate trade-offs in Kenyan peri-urban vegetable production. *Agricultural Systems* 160, 79-86.

Lee, D. R. (2005). Agricultural sustainability and technology adoption: issues and policies for developing countries. *American Journal of Agricultural Economics*, 87, 1325–1334.

Lin, C. J., Jensen, K.L., & Yen, S.T. (2005). Awareness of foodborne pathogens among US consumers. *Food Quality Preference*, 16(5), 401–412.

Marenya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy, 32*(4), 515-536. doi:10.1016/j.foodpol.2006.10.002

Mbaga-Semgalawe, Z., & Folmer, H. (2000). Household adoption behaviour of improved soil conservation: the case of the North Pare and West Usambara Mountains of Tanzania. *Land Use Policy.* 17, 321–336.

The Montpellier Panel. (2013). *Sustainable Intensification. A new paradigm for African agriculture*. Lomdon: Imperial College.

Muhanji, G., Roothaert, R. L., Webo, C., & Stanley, M. (2011). African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. *International Journal of Agricultural Sustainability, 9*(1), 194-202. doi:10.3763/ijas.2010.0561

Mulwa, C., Marenya, P., Rahut, D. B., & Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management*, 16, 208-221. doi:10.1016/j.crm.2017.01.002

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117-127. doi:10.1016/j.foodpol.2014.06.010

Ngugi, I. K., Gitau, R., & Nyoro, J. (2007) Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya: re-governing markets innovative practice series. International Institute for Environment and Development, London.

Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., & Mukhwana, E. J. (2006). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems,* 76(2-3), 153-170. doi:10.1007/s10705-005-7126-7

Onium, M. & Mwaninki, P. (2008). Cataloguing and evaluation of available community/farmers-based seed enterprise on African indigenous vegetables for ECA countries. Lagrotech Consultants.

Pender, J. L., & Kerr, J. M. (1998). Determinants of farmers' indigenous soil and water conservation investments in semi-arid India. *Agricultural Economics*, 19, 113–125.

Pincus, L., Margenot, A., Six, J., & Scow, K. (2016). On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in central Uganda. *Agriculture, Ecosystems & Environment, 225*, 62-71. doi:10.1016/j.agee.2016.03.033

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1), 5-24. doi:10.3763/ijas.2010.0583

Rogers, E.M. (2003). *Diffusion of Innovations*. 5th Edition, Free Press, New York.

Shackleton, M.C., Pasquini, M.W., Dresher, W.A. (2009). *African Indigenous Vegetables in Urban Agriculture*. Earthscan Publishers, London.

Shiferaw, B. A., Okello, J., & Reddy, R. V. (2007). Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, Development and Sustainability, 11*(3), 601-619. doi: 10.1007/s10668-007-9132-1

Stöber, S., Chepkoech, W., Neubert, S., Kurgat, B., Bett, H., & Lotze-Campen, H. (2017). *Adaptation Pathways for African Indigenous Vegetables' Value Chains,* 413-433. doi: 10.1007/978-3-319-49520-0_25

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labour. *Ecological Economics*, 93, 85-93.

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, 515(7528), 518-522.

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2007). Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. *Nutrient Cycling in Agroecosystems*, 76, 171-182.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of Integrated Soil Fertility Management. Plant Soil, 339, 35–50

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., & Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, 8, 15-22. doi:10.1016/j.cosust.2014.06.001

Vignola, R., Harvey, C. A., Bautista-Solis, P., Avelino, J., Rapidel, B., Donatti, C., & Martinez, R. (2015). Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. *Agriculture, Ecosystems & Environment*, 211, 126-132.

Waithaka, M. M., Thornton, P. K., Shepherd, K. D., & Ndiwa, N. N. (2007). Factors affecting the use of fertilizers and manure by smallholders: the case of Vihiga, western Kenya. *Nutrient Cycling in Agroecosystems, 78*(3), 211-224. doi:10.1007/s10705-006-9087

Weinberger, K., & Pichop, G.N. (2009). Marketing African indigenous vegetable along urban and peri-urban supply chain in sub-Sahara Africa. In Shackleton, M.C., Pasquini, M.W., & Dresher, W.A. (Eds.). *African Indigenous Vegetables in Urban Agriculture*. Earthscan Publishers, London. .

Chapter 3

Impacts of Sustainable Intensification of Vegetable Production on Farmers' Livelihoods in Kenya

Barnabas K. Kurgat[1*], Evans Ngenoh[2], Hillary K. Bett[2], Silke Stöber[1], Samuel Mwonga[3], Hermann Lotze-Campen [4, 5], Todd S. Rosenstock[6, 7, 8]

1. Centre for Rural Development (SLE), Humboldt-Universität zu Berlin, Hessische Str. 1-2, 10115, Berlin, Germany
2. Department of Agricultural Economics and Agribusiness Management, Egerton University, P.O. Box 536-20115, Egerton, Kenya
3. Department of Crops, Horticulture, and Soils, Egerton University, Kenya, P.O. Box 536 -20115, Egerton, Kenya
4. Potsdam Institute of Climate Impact Research (PIK), P.O. Box 601203, 14412, Potsdam, Germany
5. Department of Sustainable Land Use and Climate Change, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Germany
6. World Agroforestry Centre (ICRAF), United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
7. CGIAR Research Program on Climate Change, Agriculture, and Food Security, United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
8. World Agroforestry Centre (ICRAF), Avenue des cliniques No 13, c/o INERA, Kinshasa, the Democratic Republic of the Congo

*E-mail of the corresponding author: bkurgat@yahoo.com

This chapter has been submitted to International Journal of Agricultural Sustainability

Abstract

Sustainable intensification (SI) approach aims to increase agricultural productivity and farmers' livelihoods. However, there is limited empirical evidence on the impact of adopting SI practices (SIPs) on famers' livelihoods in Sub-Sahara African (SSA). There is need therefore to assess whether adoption of SIPs in actual sense improves farmers' livelihoods and if so, by what magnitude. This study evaluated the impact of adoption of SIPs on household income based on 685 household-level data from rural and pre-urban vegetable production in Kenya using a treatment effect model. Results show that the correlation coefficients were statistically significant. Therefore, the adoption of SIPs was influenced by both observed and unobserved factors. Further, the findings revealed that adoption of SIP increased crop income by 53.3%, while total household income increased by 12.9%. These findings highlight the need for continued public and private investments on programs and policies supporting adoption of SIPs in smallholder vegetable production as one potential option for a sustainable improvement of vegetable production and smallholder farmers' livelihoods in SSA.

Keywords: Livelihoods, smallholder farmers, sustainable intensification, vegetable production, Kenya

3.1 Introduction

Agriculture remains an important driver of livelihood advancement and food security of smallholder farmers in Sub-Saharan Africa (SSA) (AGRA, 2017). For instance, the sector supports the livelihoods and economies of up to 65% of rural populations (IFDC, 2006; OECD/FAO, 2016). In addition, increase in smallholder agricultural production has been reported to a have substantial impact on poverty eradication. For example, Thirtle et al. (2001) indicated that a 1% increase in crop yields reduces the number of poor people by about 0.7% in Africa. However, declining soil fertility, water scarcity and climate variability are some of the key factors which constraints smallholder agricultural productivity in SSA (Vanlauwe et al., 2006; Ngwira et al., 2012, Jayne et al., 2014). Sustainable intensification (SI) is one approach deemed to offer solution to these problems, i.e. aims to produce more food and farm income from existing land with less external input and fewer environmental impacts (Pretty et al., 2011; Cook et al., 2015). A number of agricultural practices have been listed in literature as suggestive of SI practices (SIPs) and includes integrated soil fertility, conservation agriculture (CA), integrated pest management (IPM), crop system diversification, use of improved seeds/varieties and sustainable water management – use of improved irrigation systems among others (Okalebo et al., 2006; Badgley et al., 2007; Dile et al., 2013).

Despite SIPs potential to improve soil fertility and crop yields, there is still limited empirical evidence on the effects of adoption on household livelihoods of smallholder farmers. Previous studies dealing on SI of agriculture mainly focused on determinants of adoption of SIPs on production of cereals crops such as maize and wheat. For instance, Marenya et al. (2007) assessed household - level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya without examining the resultant impacts on household livelihoods. Similarly, Ndiritu et al. (2014) examined gender difference in adoption of SIPs as well as factors conditioning adoption in in rural Kenya. Further, Odende et al. (2009) documented factors responsible for differences in uptake of integrated soil fertility management practices among smallholder farmers in western Kenya without assessing resulting effects on farmers' livelihoods. Similarly, other studies carried across SSA also largely focused on the rates and determinants of adoption of SIPs with no evaluation of subsequent effects on farmers' livelihoods (Abdulla et al., 2011; Kassie et al., 2013; Kama et al., 2014; Gel go et al., 2016).

Few studies have evaluated impacts of adoption of SIPs on household livelihoods (table 3.1). From their findings, a few observations can be made. First, adoption of SIPs positively increases farmers' livelihoods. However, the magnitude of the increase varies across the livelihood indicators. For instance, Methane et al. (2014) assessed the impact of using hybrid seeds of maize on livelihoods of farming households in Kenya and found a significant increase on annual household income and asset value of 7% and 9% respectively, and a 2.9% reduction on poverty. Manda et al. (2016) evaluated effects of practicing maize-legume rotation, improved maize seed and crop residue retention on household livelihoods in Zambia and found 25-62% increase on per capita household income. Similarly, adoption of SIPs (residue retention, maize-legume rotation and improved maize), in isolation as well as jointly, positively increased crop net revenue per hectare from maize-legume production in Zambia within a range of 25-62%. Adoption of SIPs also increased household food security by 2.7-9.8% (Shiferaw et al., 2014). Secondly, these studies report results of impacts of adoption of few SIPs (improved seed varieties, minimum tillage, crop residue retention, maize-legume rotation).

Table 3.1. Summary results of impacts of adoption of SIPs on livelihoods of smallholder farmers in SSA

SIPs	Crop	Location	Method of analysis	Impacts on livelihood indicators	Reference
Hybrid seed	Maize	Kenya	Tobit model with Correlated Random Effects (CRE)	Adoption increased: annual income by 7% on average and asset wealth by 9-21%	Methane et al., 2014
Improved varieties	Wheat	Ethiopia	Endogenous switching regression (ESR) model and Propensity score matching (PSM)	Increased probability of food security in the range of 2.7-9.8%	Shiferaw et al., 2014
Modern seed, conservation tillage and cropping system diversification	Maize (major) and beans (soybeans or haricot beans) as legumes	Ethiopia	Multinomial Adoption Selection Model	Increased maize income between 18 – 203 USD per ha or 497-5580 Ethiopian birr per ha. It also increase labour demand	Teklewold et al., 2013
Improved varieties	Groundnuts	Uganda	Propensity score matching	Increase crop income in the range of 130-254 USD and decrease poverty (estimated by headcount index) by 7-9% points	Kassie et al., 2011
Residue retention, maize-legume rotation and improved maize	Maize/legume (sun hemp)	Zambia	Multinomial endogenous treatment effects model	*Exogenous assumption* Increased maize yields per ha between 17% and 58% Increased household income per capita between 25% and 62% *Endogenous assumption* Affected maize yields on range of -6% and 90%	Manda et al., 2016

Table 3.1. Continued

SIPs	Crop	Location	Method of analysis	Impacts on livelihood indicators	Reference
				Affected household income per capita in the range of -12 - 75%	
Single or join use of minimum soil disturbance, crop residue retention and legume nitrogen-fixing crop rotation	Maize, groundnuts and mixed beans	Zambia	Multinomial logit selection model	Increased crop net revenue (in USD) in the range of 18.4% to 67.4% per ha	N`gombe et al., 2017

Note: USD represent US dollar.

This means that impacts of adoption of other SIPs in crop production, outside of what was considered in these studies, are uncertain or are only based on the general assumption that SIPs improve farmers' livelihoods. Thirdly, these studies did not included livelihoods outcomes from adoption of SIPs in horticultural crop production such as vegetables. Thus, while we increasingly know what determines the use of various SIPs in cereal production systems, we do not know the effects of adoption of SIPS on livelihoods of those farmers particularly involved in vegetable production. This means that there is a considerable assumption that adoption of SIPs in vegetable production improves farmers' livelihoods, but is this true?

The importance of vegetables in particular African indigenous vegetables (AIVs) has increased in the recent past. This is because AIVs have potential to generate additional household income, and food security and nutritional benefits for smallholder farmers in rural and peri-urban areas of Kenya (Ngugi et al., 2007). AIVs grows faster and have short growth cycles with some like amaranth and African nightshade are ready for first leaf harvesting within 3-4 weeks after planting (Abeokuta, 2003; Onium and Manikin, 2008). In addition, AIVs contain high levels of micronutrients and minerals compared to exotic vegetables such as spinach (Abukutsa, 2003, Ngugi et al., 2007). The importance of these AIVs has driven land area under production AIV in Kenya to increase by 31%, up from 27,102 ha in 2009 to 35,503 ha in 2014 (HCDA, 2014). This study therefore, examined the impacts of adoption of SIPs on household income, as a proxy indicator used for farmers' livelihoods, of smallholder farmers cultivating AIVs in Kenya. The study focused on three SIPs: use of improved irrigation systems (use of hosepipe-sprinklers fitted with small motor pumps to pump water from wells/rivers to crop fields), integrated soil fertility management and use of animal manure or organic inputs. Specifically, the research asked the following: (1) are there household socio-economic and institutional differences between adopters and non-adopters of SIPs? (2) what are the determinants for adoption of these SIPs? and (3) what is the impact of adoption of SIPs on smallholder household livelihoods (household income)? This study seeks to contribute to existing literature in two ways. First, we document impacts of adoption of SIPs on smallholder farm household who depend on non-cereal crops (vegetables). Secondly, we used a treatment effect model, which provides consistent estimates of impacts of adoption while accounting for sample selection bias. For instance, the model estimates direct marginal effects of SIPs on smallholder household's income, while taking into account both observable and unobservable variables (Cong and Drucker, 2000).

3.2 Methodology

3.2.1 Study site

The present study used dataset from farm household survey gathered from Kenyan rural and peri-urban regions in September-November 2016 by the Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project. Four counties in Kenya were the central focus: Kiambu and Nakuru located in peri-urban areas and Kakamega and Kisii counties, which are located in rural areas of western Kenya. These counties were chosen because they are the major areas where AIVs are cultivated and traded. Kiambu County has an altitude of1940 m and a population of 1.6 million people (KNBS, 2009). The County receives an average monthly maximum and minimum temperature of 23.8°C and 12.6°C respectively. Nakuru County on the other hand has an altitude of 1,795 m and receives annual rainfall and mean temperature of 960 mm and 17.5°C (maximum 25°C and minimum 11°C) respectively. Production of AIVs in these two counties is partly rain-fed as well irrigated (mainly during driest periods). Additionally, vegetables produced are sold locally (farm gate) as well in the nearby open urban markets, retail shops, restaurants and supermarkets. Kakamega County has an altitude of 1,535 m and receives annual rainfall ranging from 1,200 to 2000 mm, and a maximum and minimum temperature of 27 °C and 14°C respectively. Kisii County has an altitude of 1,700 m and receives annual rainfall of 2,070 mm and a maximum and minimum temperature of 25°C and 15°C respectively.

3.2.2 Data collection

Six hundred and eighty five farming households were selected through multi-stage sampling. In the first stage of sampling procedure, two production systems were selected based on their AIV production environment: rural and peri-urban. Secondly, two counties were further selected from each production system: Kakamega and Kisii were selected for the rural setting, and Kiambu and Nakuru for the peri-urban. Thirdly, five to ten divisions were randomly selected from each county based on the size of the division and the intensity of AIV production. Finally, proportionate to size sampling approach (according to village household size) was used to randomly select farm households at the village level. Given that the sampling was random, 396 household were selected from rural areas (197 and 199 from Kakamega and Kisii counties respectively) and 289 from peri-urban (144 from Kiambu and 145 from Nakuru counties). Each household was interviewed using a structured questionnaire to characterise household socio-economic and production of AIVs including management practices such as use of SIPs during 2015/2016 production season. Therefore, adopters were considered as those who use at least one of the three SIPs (improved irrigation, integrated soil fertility and use of animal/organic input) while non-adopters are those who use none. Complementary data on assets, land and livestock ownership, income sources, access to credit and extension services, marketing, distance to the nearest agro-dealer (agro vet), social networks and farmers willingness to take production risks (based on farmers perception) were also collected.

3. 2.3 Model specification

3.2.3.1 The choice of SIPs

The conceptual framework employed in this study was based on the assumption that AIV farmers choose to adopt or not to adopt SIPs. They also take into account the expected net returns (R_A^*) derived from adopting SIPs as well as expected net returns (R_{NA}^*) derived from not adoption. AIV farm households often decide to adopt SIPs, if the perceived utility or net returns from adoption (R_A^*) is significantly greater than the case for non-adoption (R_{NA}^*). Even though utility is not directly observed, the actions of smallholder AIV farmers are observed through the choices they make, for instance, they would choose to adopt SIPs if $R_i^* > 0$. Therefore, R_i^* can be expressed as a function of observable elements in the following latent variable model:

$$R_i^* = \beta Z_i + \mu_i, \qquad R_i = 1 \; if \; R_i^* > 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

where R_i is a binary indicator variable that equals 1 for household i, which has adopted at least one of the SIPs of interest in this study, and 0 otherwise if they adopted none; Z_i is a set of explanatory variables; β represents the parameters to be estimated; and μ_i is an error term assumed to be normally distributed with zero mean. The probability of smallholder AIV farmer's adopting SIPs can be expressed as:

$$\Pr(R_i = 1) = \Pr(R_i^* > 0) = \Pr(\mu_i > -\beta Z_i) = 1 - F(-\beta Z_i) \ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

where F is the cumulative distribution function for μ_i.

3.2.3.2 Impact assessment and selection bias

In order to efficiently and effectively link the decision to adopt of SIPs with their household income, we assume that rational farmers maximize their net returns from AIV production. Therefore, considering that the outcome variables (household income) has a linear function relationship with a set of explanatory variables X_i, we specified outcome equation as:

$$Y_i = \beta X_i + \alpha R_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where, Y_i represents household income; X_i is a set of explanatory variables such as household capitals, market integration, institutional factors, and access-related variables; R_i is an indicator of SIPs adoption dummy variable as defined in Eq. (3.1); β and α are parameters to be estimated, and ε_i is a random error term. In the outcome equation (Eq. 3.3), R_i is an exogenous variable, but in this study, AIV farmers may choose by themselves (self-select) to be in the adopters group, depending on their unobservable characteristics, rather than being randomly selected. This implies that Eq. (3.3) might generate biased estimates. In addition, the error terms of both the selection Eq. (3.1), and the outcome Eq. (3.3) might be correlated if they are influenced simultaneously by unobservable factors and hence yielding inconsistent estimates. Therefore, failing to account for such selectivity bias may result in inconsistent estimates. This aspect of accounting for the effects of unobservable factors requires an appropriate approach that considers the effects of both observables and unobservable factors. The study therefore, employed treatment effect model, which estimates direct marginal effects of SIPs on smallholder household's income, while taking into account both observable and unobservable variables (Cong and Drucker, 2000).

3.2.3.3 Treatments effect model

Treatment effect model was used because of its ability to directly estimate the impact of adopting SIPs on smallholder AIV farmers household's income, while addressing the problem of sample selection bias as well as taking into account both observable and unobservable variables (Cong and Drunker, 2001). The model uses maximum likelihood (ML) in the simultaneous estimation of Eq. (3.1), and Eq. (3.3). Therefore, following Cong and Drunker (2001), the treatment effect model will jointly estimate Eq. (3.1), and Eq. (3.3), and the first-stage is a selection Eq. (3.1) based on a binary outcome criterion function for the adoption of SIPs, while the second stage will represent the outcome Eq. (3.3). However, for a proper identification that allow the variables Z_i in Eq. (3.1) and X_i in Eq. (3.3) to overlap, it is important to have at least one variable in Z_i which is not included in X_i. More specifically, for the model to be identified, it is important to use an identifying instrumental variable in the Eq. (3.1) that directly affects the adoption of SIPs, but not the household income. In this study, we used distance to the nearest agro-dealer (input and extension service providers) as the identification restriction. We hypothesize that smallholder AIV farming households are not selecting their farmland in relation to proximity to the location of input providers, and hence making it an exogenous instrument to their decision of adopting SIPs. Currently, in Kenya, access to government information sources, and extension services, especially on inputs and technology use/ adoption has been on a demand driven and hence, forcing smallholder farmers to seek these services in various agro-dealers (Muyanga and Jayne, 2006; Oluoch-Kosura, 2010). Furthermore, recent studies on impacts of various technology adoptions on smallholder household welfare outcome indicators have also used similar identification restriction (Kassie et al., 2011; Shiferaw et al., 2014; Khonje et al, 2015). We performed the falsification test (Di Falco et al., 2011) and the results indicate that the instrument is a valid identifying instrument as it is not statistically significant when included in the outcome Eq. (3.3). The result also suggests that the instrument is valid because the correlation analysis reveals that the selected instrument is not correlated with household crop income and total household income. As a final robustness check, we estimated endogenous switching regression model and further determine the average treatment effect of the treated (ATT) using the coefficients from ESR model as per the recommendation of Lokshin and Sajaia (2004).

3.3 Results and discussion

3.3.1 Sample demographics

Summary statistics of demographic variables used in this study are presented in table 3.2. The results indicate that 76.7% of farm households adopted at least one SIPs of our interest while 23.3% were non-adopters. Data also revealed that, the average household size was about 6 members while average household head was 52 years old. Approximately 82% of household heads were male and the average education level was 8 years of schooling. The average land size was 0.28 acres with 89% of households owning their land. Of the farm households interviewed, 42% were located in peri-urban areas, while 58% were from rural areas.

The comparative analysis of the means of socio-demographic characteristics between adopters and non-adopters of at least one SIP are shown in table 3.3. These results show that adopters had slightly higher average level of education of between 1-2 years. Additionally, adopters were more integrated to AIV markets and were much closer to agro-dealers in terms of distance (km) – a variable used as a proxy for distance to access extension services and market inputs. For example, 73% of the adopters participated in informal market outlets, whereas only 55% of the non-adopters were integrated in informal market outlets. Of the adopters, 33% sold their AIV produce in formal market outlets while only 20% of non-adopters did. About 25% of farm household from rural areas were adopters, which is almost 50% less compared to their counterparts in peri-urban.

Table 3.2. Description and summary statistics of variables used in treatment effect model

Dependent variables	Description of the variables	Mean	Std. Dev.
SIPs	Farmers using at least one SIP (1=yes; 0=no)	0.76	0.42
Natural logarithm of household income	Total household income (KSH)	9.42	0.79
Natural logarithm of income from crops	Household income from crops only (KSH)	8.29	1.37
Explanatory variables		Mean	Std. Dev.
Household characteristics			
Household size	Total household/family size (numbers)	6.11	2.37
Household head is male	Household structure (1=male; 0=female)	0.82	0.39
Age of household head	Household head age (years)	52.70	12.64
Education level	Household head level of education (years of schooling)	8.47	4.66
Willingness to take risk†	Household head willingness to take risk (1=yes; 0=no)	0.76	0.43
Asset endowment			
Natural logarithm of land size	Natural logarithm of household land size (acres)	0.28	1.07
Farming as main occupation	Household head with farming as main occupation (1=yes; 0=no)	0.62	0.49
Livestock ownership	Household owning livestock (1=yes; 0=no)	0.97	0.16
Farm ownership	Household land ownership (1=owned; 0=otherwise)	0.96	0.19
Land fertility	Household land fertility (1=Fertile; 0=otherwise)	0.37	0.50
Market access			
Informal market integration	Household selling any of AIVs grown (1=yes; 0=no)	0.69	0.46
Formal market integration	Household participating in the formal market (1=yes; 0=no)	0.30	0.46
Natural logarithm of distance to market	Natural logarithm of distance to the nearest market (km)	0.63	0.70
Institutional factors			
Extension	Household accessing extension services (1=yes; 0=no)	0.64	0.48
Access to credit	Household accessing credit services (1=yes; 0=no)	0.24	0.42
Group membership	Household member belong to AIV farmer group (1=yes; 0=no)	0.37	0.48
Information on new agricultural technologies	Household access to information on new agricultural technologies and innovations (1=yes; 0=no)	0.38	0.49
Information on health benefits of AIVs	Household having information on health benefits of AIVs (1=yes; 0=no)	0.72	0.45

Table 3.2. Continued

Dependent variables	Description of the variables	Mean	Std. Dev
Distance to nearest agro vet	Distance to nearest agro vet in kilometers	7.43	2.43
Environmental constraints			
Crop pest	Households who faced crop pest attack (1=yes; 0=no)	0.07	0.25
Water shortage	Water shortage during the growing season (1=yes; 0=no)	0.08	0.27
Unusual heavy rainfall	Unusually heavy rainfall in the growing season (1=yes; 0=no)	0.13	0.34
Farm location			
Peri-urban	Household farm location (Peri-urban=1rural=0)	0.42	0.50

Note: † denotes farmer's willingness to take production risk based on their perceptions.

Table 3.3. Mean differences in the characteristics between adopters and non-adopters of SIPs

Variables	Adopters	Non-adopters	Difference in means
	Mean (Std. Dev)	Mean (Std. Dev)	
Household characteristics			
Household size	6.03 (2.34)	6.34 (2.44)	-0.31
Household head is male	0.81 (0.39)	0.81 (0.38)	0.00
Age of household head	52.75 (12.64)	52.51 (13.69)	0.24
Education level	8.80 (4.64)	7.38 (4.61)	1.41****
Willingness to take risk	0.76 (0.42)	0.74 (0.43)	0.02
Asset endowment			
Natural logarithm of land size	0.93 (1.87)	0.88 (2.43)	0.05
Farming as main occupation	0.62 (0.48)	0.61 (0.48)	0.01
Livestock ownership	0.96 (0.17)	0.98 (0.13)	-0.01
Farm ownership	0.97 (0.18)	0.91 (0.28)	0.06****
Land fertility	0.38 (0.48)	0.33 (0.47)	-0.05
Market access			
Informal market integration	0.73 (0.44)	0.55 (0.42)	0.17****
Formal market integration	0.33 (0.47)	0.20 (0.40)	0.12***
Natural logarithm of distance to market	0.29 (0.93)	0.20 (0.61)	0.96
Intuitional factors			
Access to extension	0.62 (0.48)	0.66 (0.47)	-0.03
Access to credit	0.22 (0.42)	0.25 (0.43)	-0.03
Group membership	0.34 (0.47)	0.33 (0.47)	0.01
Information on new agricultural technologies	0.39 (0.49)	0.37 (0.48)	0.02
Distance to nearest agro vet (km)	7.71 (2.31)	6.50 (2.57)	1.20****
Environmental constraints			
Crop pest	0.07 (0.25)	0.05 (0.23)	0.02
Water shortage	0.08 (0.27)	0.06 (0.26)	0.02
Unusual heavy rainfall	0.13 (0.33)	0.13 (0.34)	0.00
Farm location			
Peri-urban	0.47 (0.49)	0.25 (0.43)	0.21****
Household income crop crops	8.36 (1.34)	8.06 (1.42)	0.30***
Total household income	9.46 (0.78)	9.28 (0.79)	0.18***

Note: Robust standard errors are reported in parentheses.

****, ** indicates significance at $p < 0.001$, 0.01 and 0.05 respectively

Mean household income from crops and total household income for adopters were 3.7% and 2% higher than that of non-adopters, respectively. The mean values showed positive and significant difference in household income from crops and total household income between adopters and non-adopters.

3.3.2 Factors conditioning adoption

Factors conditioning the adoption of SIP(s) in AIV production are presented in column 2 and 4 in table 3.4. We discuss these factors briefly because the primary focus of this study was to evaluate the impacts of adoption of SIPs on farmers' livelihoods. The results shows that the used instrument variable was positive and significant, suggesting that farmers who were closer to input markets and extension services (agro-dealers) were more likely to intensify AIV production in a sustainable way. Shorter distance from farm to input market reduces transaction cost, especially transport cost associated with farm inputs (e.g. fertilisers and irrigation pipes). Additionally, extension services (officers) plays a significant role in disseminating knowledge on new SIPs, how to use them and potential benefits. This is also seen by the positive and significant coefficient for information on new agricultural technologies and innovations on adoption of SIPs. This result is consistent with previous studies, which investigated adoption of SIPs in cereal crop production (Kassie et al., 2011; Shiferaw et al., 2014; Khonje et al., 2015). Farm households with better level of education, own land, and have access to farmer groups were also more likely to adopt SIP, which agrees with the previous findings documented in literature (Hailu et al., 2014; Shiferaw et al., 2014; Khonje et al., 2015). Furthermore, smallholder AIV farmers who were integrated to informal AIV markets were more likely to intensify AIV production in a sustainable way. The coefficient for farm location was also significant and positive, suggesting that households residing in peri-urban areas were more likely to adopt SIPs compared to those in rural areas. This may be attributed to differences in farm location features or infrastructural development gap between peri-urban and rural areas (better road network, access to information, market outlets) that may influence farmers' investment in SIPs.

3.3.3 Impacts of adoption of SIPs on household income

The results presented in table 3.4 in column 3 and 5 are the impacts of adoption of SIPs as well as explanatory variables on crop and total household income specifications, respectively. These results revealed that adoption of SIPs positively and significantly affects both incomes in the two models, with marginal effects of 1.2 and 0.9, respectively. These marginal effects translate to 14.8% and 9.6% increase in crop and total household income respectively using sample mean values shown in table 1 as a reference point. These differences could not have been observed using descriptive statistics which don't account for endogenous selection bias and systematic difference with regard to observable and unobservable factors between adopters and non-adopters.

The coefficient of variables for household size and education of the household head were positive and significant on both incomes. These results imply that households' with larger members were likely to earn more income probably due to availability of family labour, which can be used for household crop production as well as off-farm activities. Farming activity as the main occupation of the household negatively influenced total household income. This is perhaps because full time farmers earn less than part-time farmers, who have the possibility to engage in off-farm work and generate income with higher hourly wages compared to farming. The positive effect of education on household income is consistent with the previous finding of Methane et al (2014) in Kenya, and Khonje et al. (2015) in Zambia, which found positive impacts of education on household incomes, and the significance of household labour constraints in the process of generating these incomes. In addition, Cungura and Darnhofer (2011) also found positive correlations between higher education levels of household head with household income from smallholder maize farmers in rural Mozambique. Farm households' with better-educated household heads are more likely to participate in off-farm activities, especially those that require some level of technical skills, which usually have higher returns per labour hour. A share of this revenue from off-farm activities is mostly likely to be invested in crop production hence the positive impact of education on crop income. Additionally, off-farm income is also likely to be an intermediary factor influencing adoption of SIPs, which effects household income also hence fitting into the argument that of off-farm income (work) stimulates agricultural investment. Furthermore, smallholder AIV farm households' headed by males were more likely to enhance their total household income than those headed by women. This may be attributed to the fact that male-headed households are likely to access off-farm activities particularly those that are more labour demanding but generates substantial earnings to the household. The coefficient for the age of the household head was negative and significantly different from zero on total household income. This is perhaps older persons are associated with loss of energy and does not engage in capital intensive and long term investment with high probability of better returns.

Household asset endowments were also significant in enhancing household income. For instance, farm households' with bigger land size and owners of livestock were likely to have more income from crops as well as total household income. This is evident by the positive and significant coefficient for land size and livestock ownership on income from crops and total household income. Methane et al. (2014) found similar result that the bigger the household farm size, the higher the impact on income among smallholder maize producers in Kenya.

Table 3.4. Determinants of adoption of SIPs and impacts on household income

Variable	Model (1)		Model (2)	
	Adoption	Income from crops	Adoption	Total Household income
Adoption of SIPs		1.233 (0.293)****		0.910 (0.154)****
Household size	-0.003 (0.026)	0.041 (0.023)*	-0.010 (0.025)	0.034 (0.013)**
Household head is male	0.01 (0.159)	0.141 (0.137)	0.023 (0.158)	0.167 (0.080)**
Age of household head	-0.001 (0.0046)	-0.000 (0.004)	-0.000 (0.004)	-0.004 (0.002)**
Education level	0.027 (0.012)**	0.019 (0.011)*	0.027 (0.012)**	0.003 (0.006)
Willingness to take risk	0.018 (0.135)	-0.081 (0.120)	0.005 (0.133)	0.074 (0.070)
Natural logarithm of land size	-0.079 (0.058)	0.375 (0.049)****	-0.126 (0.056)*	0.189 (0.029)****
Farming as main occupation	0.050 (0.124)	-0.032 (0.109)	0.129(0.120)	-0.188 (0.064)***
Livestock ownership	-0.250(0.374)	0.608 (0.315)*	-0.406 (0.367)	0.406 (0.184)**
Farm ownership	1.122 (0.286)****	0.507 (0.294)*	1.050 (0.284)****	0.369 (0.170)***
Land fertility	0.022(0.118)	0.176 (0.105)*	0.017 (0.118)	0.089 (0.061)
Informal market integration	0.402 (0.139)***	0.004 (0.133)	0.402 (0.137)***	0.227 (0.077)***
Formal market integration	0.016 (0.147)	0.178 (0.127)	0.042 (0.146)	0.120 (0.074)
Natural logarithm of distance to market	-0.006 (0.073)	-0.074 (0.059)	-0.004 (0.072)	-0.033 (0.035)
Access to extension	0.182 (0.128)	0.015 (0.110)	0.178 (0.125)	0.038 (0.064)
Access to credit	0.105 (0.137)	0.196 (0.123)	0.133 (0.135)	0.232 (0.0723)****
Group membership	0.255 (0.136)*	0.020 (0.122)	0.248 (0.134)*	0.065 (0.0715)
Information on new agricultural technologies	0.229 (0.128)*	0.305 (0.111)***	0.154 (0.126)	0.092 (0.065)
Crop pest	-0.114 (0.233)	-0.070 (0.200)	-0.130 (0.229)	-0.126 (0.117)
Water shortage	0.318 (0.222)	-0.242 (0.188)	0.249 (0.224)	-0.076 (0.110)
Unusual heavy rainfall	-0.024 (0.169)	-0.195 (0.152)	0.054 (0.170)	-0.087 (0.089)
Peri-urban	0.688 (0.146)****	0.120 (0.135)	0.701 (0.144)****	0.273 (0.078)****
Distance to nearest agro-vet	0.174 (0.025)****	-	0.167 (0.024)****	-
Constant	-1.767 (0.568)***	6.838 (0.501)****	-1.803 (0.555)***	8.705 (0.293)****

Table 3.4. Continued

Variable	Model (1)		Model (2)	
	Adoption	Income from crops	Adoption	Total Household income
Rho		-0.480 (0.113)***		-0.635 (0.089)****
/athrho		-0.524 (0.147)****		-0.751 (0.150)****
/lnsigma		0.265 (0.038)****		-0.270 (0.0426)****
LR test of indep. eqns.		10.35***		17.18****
Observations		685		685

Note: Robust standard errors are reported in parentheses. ****, ***, ** and * indicate significance at p<0.001, 0.01, 0.05, and 0.1 respectively.

Similarly Khonje et al. (2015), indicated that ownership of livestock (oxen) and other assets leads to significant gains in crop income as well as other household welfare indicators like consumption expenditure and food security among smallholder households in Zambia. Land fertility variable was also positive and significant on income from crops, perhaps because fertile soils enhances crop performance (high yields) with low farm inputs which will likely translates to higher income from crops.

With regard to market integration and institutional factors, the coefficients for informal market integration were positive and significant for both incomes. This positive impact of informal market access corroborates the finding of Cungura and Darnhofer (2011) which also reported positive impact of market access on household income of smallholder maize farmers in Mozambique. Access to credit services also positively influenced total household income. This implies that farm households' who access credit are more likely to have less liquidity problems, making it possible for them to make timely investments thereby increasing returns from such investments. Further, access to information regarding new agricultural technologies and innovations was positive but only on income from crops. This is consistent with the findings of Hailu et al. (2014), and Khonje et al. (2015), who also reported that information regarding new agricultural technologies and innovations increases chances of adoption, which in turn improves crop income. This is perhaps some of this technologies (e.g. improved irrigation systems) conserve water and are less labour intensive compared to traditional methods (e.g. use of watering cans). This in turn reduces labour cost while conserving water, which makes it possible to irrigate more land (if available) and/or increase irrigation period. Furthermore, the coefficient for farm location was positive and significant on total household income. This implies that household residing in peri-urban areas are more likely to generate more total household income compared to their counterparts in rural areas. Possible reasons for these differences could be due to fewer opportunities for non-farm work earnings in rural areas compared to peri-urban areas which is an important avenue to generate household income and farm investment.

For robustness check, impacts of adoption of SIPs on household income from crops as well as total household income was estimated using an endogenous switching regression (ESR) model. The results from ESR model are not reported here for purpose of keeping the paper brief but are available on request. Similar to treatment effect model, ESR model also addresses the selection bias problem accounting for both observed and unobserved factors (Lokshin and Sajaia, 2004). Therefore, only results of estimates of average treatment effects on the treated

(ATT) are presented in table 3.5. These findings indicate a positive effect SIPs adoption on crop and total household income. For instance, adoption of SIPs increases crop income 53.3% and total household income by 12.9%. The magnitude of impacts adoption of SIPs from this study was higher than a 7% increase of annual household income because of hybrid maize seed adoption in Kenya (Methane et al., 2014). In general, results from this study show that adoption of SIPs has a positive effect on farmers' household income

Table 3.5. Impacts of SIPs on crop, and total household income.

Variable	*Mean Outcome*		*ATT*	*t-Value*	*Change (%)*
	Adopters	Non-adopters			
Crop income	10.6(0.4)	6.9(0.7)	3.7	2.0**	53.3
Total income	9.7(1.9)	8.6(0.5)	1.1	1.8*	12.9

Note: ATT is the average treatment effect of the treated

3.4 Conclusion

This study evaluated the impact of adoption of SIPs – improved irrigation systems, integrated soil fertility management and use of organic (animal manure) on smallholder famers' livelihoods in Kenya. The results revealed positive and significant impact of adoption on income from crops as well as total household income. The magnitude of impacts of SIPs was higher on crop income compared to corresponding effects on total household income. This because crop income is a small fraction of total household income specifically in regions where significant off-farm income is possible. The findings also shows strong positive effects of to credit access, land size and farm location (peri-urban) on total household income. Household variables (household size and gender), land and livestock ownership, market integration also effected total household income positively which is consistent with the results from previous studies. Level of education, land size and access to information regarding new agricultural technologies on the other hand positively influenced household income crops.

Even though this study is limited in scope - we considered only two indicators of farmers' livelihoods – these the findings adds on to the emerging consensus of empirical evidence that adoption of SIPs improves farmers' livelihoods (household income, revenue from crops). Therefore, there is need for continued public and private investments in policy process that support adoption of SIPs in smallholder vegetable production. Such policy processes and programs should also aim to integrate more smallholder farm household in AIV markets, build household financial capital base as well as timely and effective dissemination of information regarding new agricultural technologies. Rigorous analysis that uses better methods and data sets (e.g. panel data methods, which captures time dimension) are needed to improve the understanding of impacts adoption SIPs in AIV production on farmers' livelihoods over a longer period of time.

Acknowledgments

This study is part of the Horticultural Innovations and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project funded by the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry of Economic Cooperation and Development (BMZ) within the framework of the GlobE – Global Food Security programme (Ref : FKZ 031A248A). The authors are equally grateful to the farm households for allowing us to interview them. Equally, we are thankful to Egerton University for their support in organising the logistics for the survey.

Reference

Abdulla, A., Owes, V., & Baking, J. A. (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, 70(7), 1415-1423. doi:10.1016/j.ecolecon.2011.03.004

Abukutsa-Onyango, M. O. (2003). Unexploited potential of indigenous African vegetables in Western Kenya. *Maseno Journal of Education Arts and Science*, *4*(1), 103-122.

Alliance for a Green Revolution in Africa (AGRA) (2017). *Africa Agriculture Status Report: The Business of Smallholder Agriculture in Sub-Saharan Africa.* Nairobi, Kenya: Issue No. 5.

Badgley, C., Mightier, J., Quintero, E., Zaeem, E., Chappell, M.J., Aviles-Vázquez, K., Samul on, A., & Perfecto, I. (2007). Organic agriculture and the global food supply. *Agriculture and Food Systems* 22 (2), 86–108. oi:http://dx.doi.org/10.1017/S1742170507001640.

Cong, R., & Drukker, D. M. (2001). Treatment effects model. *Stata Technical Bulletin*, *10*(55).

Cungura, B., & Darnhofer, L. (2011). Assessing the impact of agricultural technologies on household income in rural Mozambique. *Food Policy* 36: 378-390.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.

Dile, Y. T., Karlberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agriculture, Ecosystems & Environment*, 181, 69-79. doi:10.1016/j.agee.2013.09.014

Gel go, B., Mshenga, P., & Zemedu, L. (2016). Analysing the Determinants of Adoption of Organic Fertilizer by Smallholder Farmers in Shashemene District, Ethiopia. *Journal of Natural Sciences Research*, 6(19), 35-44.

Godfray, J. (2015). The debate over sustainable intensification. *Food Security*, 7, 199-208.

Hailu, B. K., Abrha, B. K., & Weldegiorgis, K. A. (2014). Adoption and impact of agricultural technologies on farm income: Evidence from southern Tigray, northern Ethiopia. *International Journal of Food and Agricultural Economics*, *2*(4), 91.

HCDA. (2014). National horticulture validated report. Kenya: Ministry of Agriculture, Department of Horticultural Crops Development Authority.

IFDC. 2006. Agricultural production and soil nutrient mining in Africa. http://www.newscientist.com/article/dn8929-soil-health-crisis-threatens-africas-food-supply.html, Accessed date: 20 October 2017.

Kama, M., Smale, M., & Mutua, M. (2014). Farmer demand for soil fertility management practices in Kenya's grain basket'. *Food Security*, 6, pp. 793–806.

Kassie, M., Shiferaw, B., & Muricho, G. (2011). Agricultural technology, crop income, and poverty alleviation in Uganda. *World Development*, *39*(10), 1784-1795

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80(3), 525-540. doi:10.1016/j.techfore.2012.08.007

Kenya National Bureau of Statistics (KNBS). (2009). Kenya population and housing highlights. Government printer, Nairobi, Kenya.

Khonje, M., Manda, J., Alene, A. D., & Kassie, M. (2015). Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia. *World Development, 66*, 695-706. doi:10.1016/j.worlddev.2014.09.008

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *Stata Journal*, *4*, 282-289.

Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia. *Journal of Agricultural Economics, 67*(1), 130-153. doi:10.1111/1477-9552.12127

Marenya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy, 32*(4), 515-536. doi:10.1016/j.foodpol.2006.10.002

Methane, M. K., Smale, M., & Olwande, J. (2014). The impacts of hybrid maize seed on the welfare of farming households in Kenya. *Food Policy, 44*, 262-271. doi:10.1016/j.foodpol.2013.09.013

Muhanji, G., Roothaert, R. L., Webo, C., & Stanley, M. (2011). African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. International Journal ofAgricultural Sustainability, 9(1), 194–202.

Muyanga, M., & Jayne, T. S. (2006). *Agricultural extension in Kenya: Practice and policy lessons*. Egerton University. Tegemeo institute of agricultural policy and development.

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117-127. doi:10.1016/j.foodpol.2014.06.010

Gnome, J. N., Kalinda, T. H., & Tembo, G. (2017). Does adoption of conservation farming practices result in increased crop revenue? Evidence from Zambia. *Agrekon, 56*(2), 205-221. doi:10.1080/03031853.2017.1312467

Ngugi I., K., Gitau, R., Nyoro, J. (2007). Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya: re-governing markets innovative practice series. International Institute for Environment and Development, London

Ngwira, A. R., Aune, J. B., & Mkwinda, B. S. (2012). On-farm evaluation of yield and economic benefits of short term maize-legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research*, 132: 149–157.

OECD/FAO. (2016). *OECD-FAO* Agricultural Outlook 2016-2025, OECD Publishing, Paris. http://dx.doi.org/10.1787/agr_outlook-2016-en*,* Accessed date: 15 October 2017

Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., . . . Mukhwana, E. J. (2006). Available technologies to replenish soil fertility in East Africa. Nutrient Cycling in Agroecosystems, 76(2-3), 153-170. doi:10.1007/s10705-005-7126-7

Oluoch-Kosura, W. (2010). Institutional innovations for smallholder farmers' competitiveness in Africa. *African Journal of Agricultural and Resource Economics*, 5(1), 227-242.

Onium, M., & Mwaninki, P. (2008). Cataloguing and evaluation of available community/farmers-based seed enterprise on African indigenous vegetables for ECA countries. Lagrotech Consultants

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1), 5-24. doi:10.3763/ijas.2010.0583

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272-284.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labour. *Ecological Economics*, 93, 85-93.

The Montpellier Panel Report. (2013) Sustainable Intensification: A New Paradigm for African Agriculture, London

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. *Nutrient Cycling Agroecosystems*, 76:171-182.

Chapter 4

Livelihood and climate trade-offs in Kenyan peri-urban vegetable production

Barnabas K. Kurgat[1*], Silke Stöber[1], Samuel Mwonga[2], Hermann Lotze-Campen [3, 4], Todd S. Rosenstock[5, 6, 7]

1. Centre for Rural Development (SLE), Humboldt-Universität zu Berlin, Hessische Str. 1-2, 10115, Berlin, Germany
2. Department of Crops, Horticulture, and Soils, Egerton University, Kenya, P.O. Box 536, Egerton, Kenya
3. Potsdam Institute of Climate Impact Research (PIK), P.O. Box 601203, 14412, Potsdam, Germany
4. Department of Sustainable Land Use and Climate Change, Faculty of Life Sciences, Humboldt Universität zu Berlin, Germany
5. World Agroforestry Centre (ICRAF), United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
6. CGIAR Research Program on Climate Change, Agriculture, and Food Security, United Nations Avenue, Gigiri, P.O. Box 30677-00100 GPO, Nairobi, Kenya
7. World Agroforestry Centre (ICRAF), Avenue des cliniques No 13, c/o INERA, Kinshasa, the Democratic Republic of the Congo

*E-mail of the corresponding author: bkurgat@yahoo.com

This chapter is published in Agricultural Systems Vol. 160, 79-86, 2018

Reprinted by permission of Elsevier Science Publishers, B.V., Amsterdam

Abstract

Trade-offs between livelihood and environmental outcomes due to agricultural intensification in sub-Saharan Africa are uncertain. The present study measured yield, economic performance and nitrous oxide (N_2O) emissions in African indigenous vegetable (AIV) production to investigate the optimal nutrient management strategies. In order to achieve this, an on-farm experiment with four treatments – (1) 40 kg N/ha diammonium phosphate (DAP), (2) 10 t/ha cattle manure, (3) 20 kg N/ha DAP and 5 t/ha cattle manure and (4) a no-N input control – was performed for two seasons. Yields and N_2O emissions were directly measured with subsampling and static chambers/gas chromatography, respectively. Economic outcomes were estimated from semi-structured interviews (N=12). Trade-offs were quantified by calculating N_2O emissions intensity (N_2OI) and N_2O emissions economic intensity (N_2OEI). The results indicate that, DAP alone resulted at least 14 % greater yields, gross margin and returns to labour in absolute terms but had the highest emissions ($p = 0.003$). Productivity-climate trade-offs, expressed as N_2OI, were statistically similar for DAP and mixed treatments. However, N_2OEI was minimized under mixed management ($p = 0.0004$) while maintaining productivity and gross margins. We therefore conclude that soil fertility management strategies that mix inorganic and organic source present a pathway to sustainable intensification in AIV production. Future studies of GHG emissions in crop production need to consider not only productivity, but economic performance when considering trade-offs.

Keywords: African indigenous vegetables, nitrous oxide emission intensity, nitrous oxide emission, soil fertility, Kenya

4.1 Introduction

Africa accounts for 16.4% of the world's N_2O emissions, of which 42% (excluding grassland and savannah burning) results from agriculture (Hickman et al., 2011). Agriculture generates N_2O emissions due to chemical fertiliser and animal manure use (Syakila and Kroeze, 2011). N_2O is released when N in the fertiliser materials is converted to N_2O gas through two microbial-mediated processes: nitrification and denitrification. Nitrification is the oxidation of ammonia to nitrate and denitrification is the reduction of nitrate and nitrite to dinitrogen gas (Mosier et al., 1998; Robertson and Groffman, 2007). The amount of N_2O produced during nitrification and denitrification depends on management and environmental factors, including the amount of N in the fertilising material, soil temperature, soil moisture/precipitation, soil physical properties, pH, available soil carbon and tillage practice (Shcherbak et al., 2014; Kim et al., 2016).

However, the climate impacts of fertiliser use need to be considered in relation to its benefits to society. This is particularly important in Africa, where agriculture supports both livelihoods and economies. The livelihoods of two thirds of the population come from agriculture (IFDC, 2006) and on average it contributes 25 % of gross domestic product (Africa Agriculture Status Report, 2016). Furthermore, the importance of fertiliser in African agricultural production is predicted to increase. Population trends and dietary patterns due to urbanisation and affluence are expected to increase food demand, driving agricultural intensification and additional fertiliser use (Tilman and Clark, 2015). Intensification of nutrient use may stimulate higher N_2O emissions by comparison with current levels. It is essential to have an improved understanding of the potential trade-offs between the N_2O emissions and productivity of farming systems in the development of environmentally friendly farm management strategies that also meet livelihood needs.

The extent of livelihood and environmental trade-offs from fertiliser use is uncertain, especially in farming systems in sub-Saharan Africa (SSA). Only a few studies have investigated N_2O emissions from African soils. These studies report N_2O emissions per unit land area and range from -0.1 to 113 kg N_2O-N $ha^{-1}yr^{-1}$. For instance, Dick et al. (2008) measured N_2O emissions from a cereal/legume rotation growing in alfisol soils in Mali and found N_2O emission levels of 0.6-1.5 kg N_2O-N $ha^{-1}yr^{-1}$. This was on average 20% lower than N_2O emissions from ten fields in humic nitisol soils with vegetables, pasture, tea, maize, cassava and forage feed on smallholder farms in east Africa (Rosenstock et al., 2016). However, N_2O emissions from intensive urban vegetable gardens tend to be high and are the sources of the high cumulative N_2O fluxes reported in African soils, *i.e.* 34-113.4 kg N_2O-N $ha^{-1}yr^{-1}$ (Predotova et al., 2010; Lompo et al., 2012).

Of those studies that have been produced *in situ* measurements of emissions in SSA, few accompany measurements of emissions with yield data of which all are from soils treated with chemical N (Nyamadzawo et al., 2014a; Hickman et al., 2014; Hickman et al., 2015; Pelster et al., 2017). The results from some of these studies indicate greater N_2OI, calculated by expressing N_2O emission as a function of yield, from soils treated with no or high N inputs. For example, Nyamadzawo et al. (2014a) reported a 94% reduction in N_2OI of rape (*Brassicas napus*) in Zimbabwe from soils amended with 65 kg N ha^{-1} compared to adjacent plots treated with no N and N fertilisation at 240 kg N ha^{-1}. N fertilisation at 75 and 100 kg N ha^{-1} reduced

N_2OI of maize yield in Kenya by 7% and 28.6% when compared to no N and N fertiliser application at 200 kg N ha^{-1} respectively, although there was no response to fertiliser addition in crop yields (Hickman et al., 2014). In general, these studies demonstrate that moderate nutrient intensification increases crop yields without necessarily increasing N_2O emissions, as was suggested by Shcherbak et al. (2014) based on a global meta-analysis. However, the underlying dataset only contained one study from Africa indicating that despite increased attention being paid to N_2O and yield trade-offs globally (van Groenigen et al., 2010; Linquist et al., 2012), our understanding of the extent of livelihood and climate trade-offs due to soil fertility management in SSA is limited.

The shift in focus to include productivity with climate objectives is promising. However, productivity is only a small part of what drives on-farm decision-making. Farmers, especially those that are market-oriented such as African indigenous vegetable (AIV) producers in peri-urban systems, typically make production decisions based on economics (Okello et al., 2014). No previous studies in SSA or elsewhere globally have investigated the trade-offs between economics and GHGs due to farm management practices in the same way as N_2OI. This is problematic because productivity and economic viability do not always follow the same pattern, *e.g.* yields might increase but net revenues fall due to increased costs of production (Pimentel et al., 2005). Therefore, it is imperative to examine trade-offs not only between productivity and emissions, but also between the economic viability of farming systems and emissions.

The present study investigated productivity and economic and climate trade-offs in soil fertility management strategies in smallholder AIV production in Kiambu county, Kenya. The importance of vegetables, particularly AIVs, has increased in Kenya due to their contribution to food security, human nutrition and income diversification for smallholder farmers (Ngugi et al., 2007; Abukutsa-Onyango, 2010). AIVs in Kenya are characterised by multiple planting and harvesting cycles throughout the year, diverse production systems depending on their location (urban, peri-urban or rural), use of either organic, inorganic or a mix of N inputs, and their degree of market integration (Shackleton et al., 2009). Therefore, the importance of AIVs to Kenya's food security and their intensive production practices make them a good model system for studying economic and climate trade-offs in soil fertility management strategies. Kiambu was chosen because it is a centre of peri-urban AIV production. We hypothesised that current N fertilisation strategies commonly used in smallholder AIV production do not generate significantly different N_2O emission profiles, and thus can be optimised to meet yield, economic outcome and environmental goals.

4.2 Materials and methods

4.2.1Study site

An on-farm experiment was established in Wangige, Kiambu county, Kenya (1° 13'12.672" N, 36° 41'54.936''E, altitude: 1940 m) on a site that is representative of peri-urban smallholder AIV production in the area. The site has been under smallholder AIV cultivation for the past six years. During that period, vegetables have been grown during the two rainy seasons each year. The 'long rains' are from mid-March to mid-June while the 'short rains' fall from October to mid-December. The region receives a mean annual rainfall of about 950 mm and has an average monthly maximum and a minimum temperature of 23.8 °C and 12.6 °C respectively. The soils are broadly classified as Humic Nitisols (Kimetu et al., 2006).

4.2.2 Experimental design and treatments

The experiment spanned two growing seasons: short rains in 2015 (season I) and long rains in 2016 (season II). The experiment was completely randomised with three replicates of four treatments.

Table 4.1. Agronomic practices for African nightshade vegetable production during both growing seasons

Season	Land preparation	Planting/ fertiliser application	Thinning	Weed/pest management	Harvesting
1	12/9/15-1st ploughing by hand, 19/10/15-2nd ploughing (making soils fine for planting)	20/10/15- Sowing seeds and fertiliser application by hand	11/11/15- Thinning	17-18/11/15- Weeding by hand 19/11/15- application of pesticide	26/11/15-1st harvesting 19/12/15-2nd harvesting
2	26/3/16- Ploughing by hand	9/4/16- Sowing seeds and fertiliser application by hand	23/4/16- Thinning and gapping	30/4/16- Weeding by hand 3/5/16- application of pesticide	13/5/16-1st harvesting 11/06/16-2nd harvesting 23 July-3rd last harvest

The treatments were a no-input control and three varying nitrogen sources: (1) diammonium phosphate (DAP, 18:46:0) at a rate of 40 kg N ha^{-1}, (2) manure at a rate of 10 t fresh cattle manure ha^{-1} (29.5 kg N ha^{-1}), and (3) a mixture of DAP and manure applied at 34.7 kg N ha^{-1} (20 kg N from DAP and 14.7 kg N derived from 5 t of fresh cattle manure ha^{-1}) for each season. The treatments were applied once at the beginning of each rainy season (20/10/15-season I and 9/4/16-season II) at the same time as fertilisation was being undertaken by other farmers in the area. The selected treatments and application rates represented soil fertility strategies commonly practised by smallholder AIV farmers in Kiambu (HORTINLEA household survey, 2014). Each plot measured 9 m^2 (3 m x 3 m) with a 1-m buffer. African nightshade *(Solanum scabrum*) seeds were incorporated 15 cm apart in rows with 40 cm between the rows. Plot management was in line with local practice and is summarised in table 4.1.

4.2.3 Productivity

Vegetables in N-treated plots were harvested twice in season I and three times in season II (Table 4.1) and the control plots were harvested once in season I and twice in season II. This is because vegetables in control plots grew at a slower rate compared to other plots. Therefore, by the time of the harvest, vegetables had not developed more than three branches, which were needed to carry out the first harvest. Consequently, by harvesting vegetables once (season I) and twice (season II) from control had no significant effect on the total yields. The harvesting procedure matched farmer's common practice. Fresh edible leaves and young stems were cut manually from each vegetable plant with more than three branches, leaving a basal stem to regrow. The same harvesting procedure was followed at each harvesting except during the final harvest of each season where all the above ground biomass was removed by cutting all the vegetables at the soil surface. Fresh yields from each subplot were weighed once in the field at each harvesting using a portable digital weighing scale (Vigo brand). Seasonal vegetable yields were determined for each treatment by totalling the weight of all the fresh vegetables harvested in each season. The total vegetable yield for each plot was obtained by summing seasonal yields from both seasons. The fresh weight of freshly harvested vegetables was used to determine vegetable yields because AIVs are usually sold in the market with prices and returns based on fresh weights.

4.2.4 N_2O fluxes

Gas samples were collected between 10 am and 1 pm throughout the experimental period. Gas sampling occurred one to three times per week depending on soil management and the expected flux. Samples were collected using vented static chambers (Parking and Venterea, 2010). Each chamber comprised a lid (27 x 37.2 x 12.5 cm) and a base (27 x 37.2 x 10 cm) clipped together tightly using metallic clamps to avoid gas leakage. Chamber bases were inserted 5-7 cm into the soil one week before the first sampling. The chambers remained in place throughout the season. They were fitted with 50 cm vents (2.5 cm in diameter), gas sampling ports and thermometers to measure internal temperatures, as also described in previous studies (Rosenstock et al., 2016; Tully et al., 2017). Vegetation was not allowed to grow inside the chamber bases. Weeds and other plants growing in the chamber bases were cut to soil height before measurements were taken.

The chambers were closed for 30 minutes during each sampling event and gases taken at 10-minute intervals from each chamber using the gas pooling method (Arias-Navarro et al., 2013). Gas samples were collected by 60 mL plastic syringes with a stopcock valve and a sampling needle, and immediately transferred to pre - evacuated 20 mL sealed glass vials. The vials were over-pressured to minimise the chance of leakage or contamination. Samples were analysed at the Word Agroforestry Centre (ICRAF) and the International Livestock Research Institute (ILRI) in line with procedures outlined by Butterbach-Bahl et al. (2016).

4.2.5 Soils

Prior to the start of the experiment, soil samples were collected at a depth of 0-20 cm and 20-50 cm in a zigzag pattern from four points in each plot. The four sub-samples from each soil depth were then mixed thoroughly and a 500 g composite sample taken for laboratory analysis. A composite sample of manure was also collected from a heap of manure to be analysed alongside the soil samples. Soil pH was determined in 1:25 (soil water) suspension. Soil texture was analysed using a Bouyoucos hydrometer after pre-treatment with H_2O_2 to remove organic matter (Okalebo et al., 2002). Total N and the organic carbon of the soil and manure samples were analysed by elementary analysis using a C/N analyser (Thermal Scientific Flash EA 1112). Samples for soil bulk density were collected from the undisturbed soil surface using a 100 cm^3 coring ring and calculated from the weight of the oven-dried soil sample (at 105 °C for 48 hours).

During the experiment, soil samples from each treatment were taken periodically, when resources allowed, at a depth of 0-10 cm. Samples were mixed evenly to obtain a composite sample for each treatment to determine the inorganic N and soil moisture content. Samples for inorganic N – ammonium (NH_4^+) and nitrate (NO_3^-) – were immediately transferred and kept in cool boxes while being transported to the laboratory for analysis. Extraction of soil inorganic N was performed within 12 hours of sampling by shaking 20 g fresh soils with 100 ml of 2MKCl solution for 60 minutes. The solution was filtered using Whatman filters, frozen and then analysed for the concentration of NO_3^- -N and NH_4^+ -N using an ultraviolet spectrophotometer (Aquakem 200: Thermo Scientific). Total inorganic N for each treatment was obtained by adding NO_3^- -N and NH_4^+ -N together. Field-moist soils were weighed, oven dried for 48 h at 105 °C and then reweighed to calculate soil moisture, expressed as water-filled pore space (WFPS) and corrected on the basis of soil bulk density and volumetric water content.

4.2.6 Economic performance

Costs of production were determined based on a survey of 12 smallholder farmers cultivating African nightshade, with three farmers per treatment (soil management strategies). Data on inputs, labour, and other costs as well as the revenue (returns to land) from the African nightshade cultivated were obtained by interviewing the selected farmers using a structured questionnaire. The economic performance of each treatment was calculated based on the costs derived from the survey.

4.2.7 Rainfall

Rainfall during the experimental period was measured using two rain gauges. The rain was measured manually every day using a graduated cylinder. Air temperature and soil temperature at a depth of 10 cm were measured using portable digital thermometers during each gas sampling event.

4.2.8 Data analysis

Cumulative estimates of N_2O emissions from each treatment were calculated for seasons I and II according to their respective growing periods. Seasonal cumulative emissions and mean fluxes for each treatment were estimated based on the total growing period of the two growing seasons. This was done based on the mean flux of the three chambers in each treatment plot and linearly interpolated between sampling events using the trapezoidal rule. Seasonal N_2O emission factors for DAP, manure and mixed were calculated following the method used by Rashti et al. (2015) as follows:

$$\mathrm{EF}\ (\%) = \frac{\mathrm{N_2O\ emission_{N\ treatment}} - \mathrm{N_2O\ emission_{control}}}{\mathrm{N_{input}}} \times 100 \quad (4.1)$$

where EF (%) is N_2O emission factor in percentage, N_2O emission $_{\text{N treatment}}$ is N_2O emission in N input, N_2O emission $_{\text{control}}$ is control treatments with no N fertilizer additions(kg N_2O-N ha^{-1}), and N $_{\text{input}}$ is the amount of added N (kg N ha^{-1}).

Gross margin (GM) analysis was used in the economic evaluation of each soil fertility management strategy and was calculated as revenue minus variable production cost. The benefit-cost ratio (BCR) was estimated by dividing GM by the total variable cost.

Nitrous oxide emission intensity per unit kg of fresh vegetable yield (N_2OI) was calculated by dividing the seasonal cumulative N_2O emissions for each treatment by the corresponding total fresh vegetable yields. Similarly, nitrous oxide emission economic intensity (N_2OEI) was determined by dividing the seasonal cumulative N_2O emissions for each treatment by the corresponding GM. Differences between the effects of the different treatments on N_2O emissions per land area, total vegetable yield, GM, N_2OI and N_2OEI were tested *via* ANOVA using SPSS (version 23). Furthermore, the effects of the main driving factors on N_2O emissions were determined by pairwise correlations using SPSS.

4.3 Results

The two growing seasons spanned 278 days. Season I started on 2 September and ended on 19 December 2015, lasting a total of 120 days. Season II comprised 158 days, starting on 24 February and ending on 30 July 2016. November received the highest mean monthly rainfall of 227 mm, while February was the driest month with no precipitation (Fig. 4.1). Soil temperature ranged from 15.7 to 24.8 °C with a seasonal mean of 20.2 °C. Air temperature ranged from 14.5 °C to 25.1 °C with a seasonal mean of 20.3 °C.

4.3.1 Soil characterisation

Soil physical and chemical properties were similar in all the experimental plots (Table 4.2). Average soil bulk density was 0.8 g cm^{-3} while the pH was 6. Total soil nitrogen (TN) in the top 20 cm soil depth was 0.3% whereas at 20-50 cm it was 0.2%. Soil organic carbon in the top 20 cm and 20-50 cm soil were 3.1% and 2.5 % respectively. Total nitrogen obtained from the manure sample was 1.6%, while the total carbon content was 23%.

4.3.2 N_2O fluxes

N_2O emission from the DAP treatment increased after N fertilisation and the onset of rainfall, reaching 57.14 µg N_2O-N $m^{-2}hr^{-1}$ (10/11/15) before gradually declining to 23.4 µg N_2O-N $m^{-2}hr^{-1}$ after one week (Fig. 4.1). The fluxes then increased again steadily for a further two weeks (to a maximum of 60.6 µg N_2O-N $m^{-2}hr^{-1}$ on 1/12/015) before decreasing to 31.5 µg N_2O-N $m^{-2}hr^{-1}$. As in season I, DAP had the largest N_2O fluxes in season II.

However, N_2O emissions remained elevated (above 55 µg N_2O-N $m^{-2}hr^{-1}$) for a longer period (about three weeks) from 28/4/16 to 21/5/16 (except on 5/5/16 when it reduced to 25 µg N_2O-N $m^{-2}hr^{-1}$), before gradually declining to background emission levels for the rest of the growing period. The temporal pattern of N_2O emissions from the manure and control treatments were comparable and below 15 µg N_2O-N $m^{-2}hr^{-1}$ across the two seasons. The fluxes from the mixed treatment were similar to those of the manure and the control except for 26/10/15 and 6/11/15 (season I) and 18/4/16 to 5/5/16 (season II) when N_2O emissions were higher (between 15.3 and 29.5 µg N_2O-N $m^{-2}hr^{-1}$). The lowest N_2O flux was recorded from the manure treatment at 0.7 µg N_2O-N $m^{-2}hr^{-1}$ (Fig. 2).

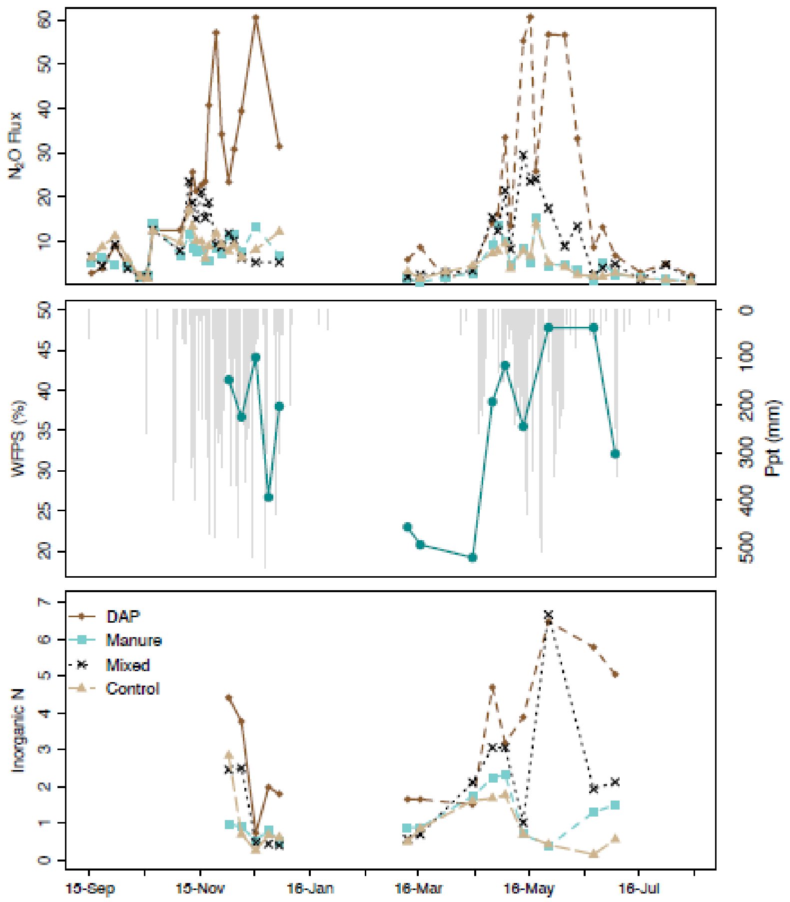

Figure 4.1. N_2O (µgN_2O-Nm^{-2} h^{-1}) fluxes for the two growing seasons (seasons I and II), WFPS (%) at 10 cm soil depth, precipitation (mm) and inorganic N (kg ha^{-1}) for the DAP, manure, mixed and control treatment plots.

Cumulative N_2O emissions from the DAP treatment for season I and seasonal cumulative N_2O emissions were significantly higher ($p = 0.003$) than those from the three other treatments, which were similar to one another. In season II, the seasonal cumulative N_2O emission from manure and the control were also similar and significantly lower than those from the DAP and mixed treatments, which were also dissimilar ($p = 0.003$) from one other.

Emission factors for DAP, and mixed treatments were 2.6% and 0.7% respectively while manure treatment had zero EF (Table 4.3).

4.3.3 Soil inorganic nitrogen and WFPS

The temporal pattern of total soil inorganic N concentrations from each treatment was similar to the corresponding N_2O emissions from each treatment across both seasons (Fig. 4.1). Total inorganic N (kg ha^{-1}) in dry soil varied from a high of 6.5 (DAP) to a low of 0.14 from the control (Fig. 1). The soil NO_3^-N in the dry soil ranged from a maximum of 5.3 (DAP) to a minimum of 2.0 (control) kg NO_3^-N ha^{-1}, whereas NH_4^+-N was between 3.3 (DAP) and 0.02 (manure) kg NH_4^+-N ha^{-1}. Soil WFPS varied from 17.9% to 48.7%, with a mean of 33.7%.

Table 4.2**.** Soil characterisation

Plots	Depth in cm	Bulk density (g cm^{-3})	pH	Soil texture			TN (%)	Total C (%)	Organic C (%)
				sand	silt	clay			
1	0-20	0.8	6.0	4.3	9.7	85.9	0.3	3.5	3.5
	20-50			1.1	6.2	92.5	0.2	2.8	2.8
2	0-20	0.8	5.9	3.7	18.0	78.1	0.3	3.4	3.4
	20-50			1.1	7.8	91.0	0.2	2.4	2.5
3	0-20	0.8	5.9	3.2	13.6	83.1	0.3	3.6	3.6
	20-50			1.7	12.4	85.7	0.2	2.5	2.6
4	0-20	0.9	6.0	3.5	10.1	86.2	0.3	3.4	3.5
	20-50			1.5	16.1	82.3	0.2	2.6	2.5
5	0-20	0.8	6.0	3.8	17.7	78.4	0.3	3.2	3.2
	20-50			1.3	9.7	88.8	0.2	2.1	2.2
6	0-20	0.8	6.0	4.1	16.8	79.0	0.2	2.9	3.1
	20-50			0.5	3.9	95.5	0.1	2.1	2.0
7	0-20	0.8	6.0	2.8	19.2	77.9	0.2	3.1	3.0
	20-50			1.1	5.8	92.9	0.2	2.0	2.1
8	0-20	0.9	6.0	4.2	11.6	84.1	0.3	3.2	3.2
	20-50			1.6	6.7	91.6	0.2	2.3	2.2
9	0-20	0.8	6.0	3.6	10.0	86.2	0.2	3.0	3.2
	20-50			1.4	7.5	91.0	0.1	2.1	2.1
10	0-20	0.8	6.1	1.2	6.1	92.5	0.2	2.9	2.9
	20-50			1.0	7.2	91.7	0.2	2.4	2.4
11	0-20	0.8	6.0	3.6	11.8	84.5	0.2	3.1	2.9
	20-50			1.1	6.2	92.5	0.2	2.2	2.2
12	0-20	0.8	6.0	3.3	7.2	89.4	0.3	3.1	3.1
	20-50			0.6	5.0	94.3	0.2	2.5	2.5
Manure	composite		7.4	58.9	26.4	14.5	1.6	23.0	22.0

4.3.4 Correlation between N_2O fluxes and environmental factors

N_2O fluxes were found to be significantly affected by NO_3^-N, WFPS and NH_4^+-N (Table 4.4), but not by soil temperature.

4.3.5 Yield

The highest yields (up to 20.2 t ha^{-1}) were obtained from the DAP treatment, while the control had the lowest (1.6t ha^{-1}). The mean of total yields from both seasons for the DAP, manure and mixed treatments and the control were 16.9 ± 2.4; 6.1 ± 2.1; 13.4 ± 3.3 and 2.8 ± 1.1 t ha^{-1} respectively (Table 4.5). When these means were compared, yields from the DAP and mixed treatments were similar and significantly (p = 0.0001) higher than those from the manure treatment and the control, which were similar to one another.

Table 4.3. Estimated cumulative N_2O emissions from each treatment for seasons I and II and seasonal cumulative N_2O emissions for both seasons in kg N_2O-N ha^{-1} as well as N_2O emission factor expressed in percentages (EF%).

Treatment	Season I	Season II	Seasonal cumulative	Emission factors
DAP	1.3±0.3a	1.7±0.2a	3.0±0.7a	2.6
Manure	0.4±0.1b	0.4±0.1b	0.8±0.1b	0.0
Mixed	0.6±0.1b	0.8±0.1c	1.4±0.2b	0.7
Control	0.5±0.1b	0.4±0.0b	0.9±0.1b	-

Data are the mean of three replicates with standard deviations and emission factors. Lowercase letters, within columns, indicate significant differences at p<0.05

Table 4.4. Pairwise correlations of the main driving factors of soil temperature (Temp) at 10 cm depth, WFPS (%), NH_4^+-N and NO_3^- - N on the fluxes of N_2O

	NH_4^+-N	NO_3^--N	N_2O	Temp
NO_3^--N	0.44^{**}			
N_2O	0.28^{*}	0.43^{**}		
Temp	0.19	0.04	-0.18	
WFPS	-0.08	0.21	0.50^{**}	-0.65^{**}

*, ** indicates significance at p<0.05 and 0.01 respectively

Table 4.5. Fresh yields of African nightshade vegetable (t ha^{-1}) from the on-farm experiment for each treatment for seasons I and II, and the total yields for both seasons

Treatment	Fresh vegetable yields		
	Season I	Season II	Total
DAP	8.3±1.6a	8.6±1.3a	16.9±2.4a
Manure	2.5±0.8b	3.6±0.8b	6.1±2.1b
Mixed	5.5±1.2a	7.9±1.1a	13.4±3.3a
Control	1.1±0.5b	1.7±0.49b	2.8±1.1b

Data are the mean of three replicates with standard deviations. Lowercase letters, within columns, indicate significant differences at p<0.05.

Table 4.6. Economic valuation (USD ha^{-1}) of each soil fertility strategy (treatment) based on data collected from smallholder farmers cultivating African nightshade

Variables	Treatments (soil fertility management strategies)			
	DAP	Manure	Mixed	Control
Input cost				
Seed	57.1 ± 0.0	57.1 ± 0.0	57.1 ± 0.0	57.1 ± 0.0
Fertilisers	231.1 ± 0	152.8 ± 7.7	190.3 ± 6.5	-
Pesticides/herbicides	71.4 ± 0.0	71.4 ± 0.0	71.4 ± 0.0	71.4 ± 0.0
Labour				
Land preparation	114.2 ± 0.0	114.2 ± 0.0	114.2 ± 0.0	114.2 ±0.0
Planting	41.2 ± 5.5	19.0 ± 0.0	47.6 ± 9.5	9.5 ± 0.0
Weeding	82.5 ± 10.9	107.8 ± 10.9	76.1 ± 0.0	111.6 ±0.0
Pesticides application	21.5 ± 0.0	21.5 ± 0.0	21.5 ± 0.0	21.5 ± 0.0
Harvesting	111.2 ± 0.0	57.1 ± 0.0	95.1 ± 0.0	38.1 ± 0.0
Total cost of labour	370.6 ± 9.5	319.6 ± 10.9	354.5 ± 9.5	294.9 ±0.0
Other cost	3.9 ± 0.0	-	1.9 ± 0.0	-
Total variable costs (a)	733.9±9.5a	600.8±12.5a	675.2± 12.6a	423.2±0.0a
Total labour hours	686 ± 14.0	736 ± 36.0	696 ± 16.4	607 ± 11.0
Labour productivity kg/hour	18.5 ± 0.9	8.1 ± 1.1	15.8 ± 3.0	5.1 ± 0.6
Area productivity (t/ha)	12.8 ± 0.7	5.9 ± 0.5	11.0 ± 0.6	3.1 ± 0.3
Gross output (b)	3441.7± 48	1484.5± 287	3001.3± 268	713.3 ± 74
Gross margin (b-a)	2707.8±46a	883.7±290b	2326.1±279a	290.1±74b
Gross margin labour hr^{-1}	3.9 ± 0.0a	1.2 ± 0.5b	3.3 ± 0.8a	0.5 ± 0.1b
Benefit-cost ratio (b/a)	4.6 ± 0.0a	2.4 ± 0.5b	4.4 ± 0.5a	1.7 ± 0.2b

Data are the mean with standard deviations of three replicates of each soil fertility strategy. Lowercase letters, within columns, indicate significant differences at $p<0.05$. The exchange rate was 1 USD = Ksh 103.85 on 2 January 2017

On a seasonal basis, the yields from the mixed and manure treatments obtained in season II were 30% higher than the corresponding harvest in season I. Yields from the control and DAP treatment harvested in season II were 35% and 3% higher respectively when compared to the harvest in season I.

4.3.6 Economic performance

Fertilisation from inorganic sources (DAP) showed the best economic performance in terms of GM, land and labour productivity (Table 4.6). In general, GM from the four soil fertility management strategies varied from 2707.8 to 290.1 USD ha $^{-1}$, while the benefit-cost ratio (BCR) ranged from 4.6 to 1.7. Net income per labour hour varied from 3.9 to 0.5 USD. The lowest economic performance was recorded from no N-input (control) plots.

GM, BCR and net income per labour hour from the DAP and mixed treatments were similar, but significantly ($p = 0.\ 001$) higher than those of the manure treatment and the control. The most labour intensive soil fertility management strategy was the use of manure, with a labour input of 736 working hours ha^{-1} in both seasons. The control was the least labour intensive, with 607 working hours ha^{-1} in both seasons.

4.3.7 N_2O and N_2EOI

The N_2OI for the four soil fertility management strategies varied from a low (mixed) of 0.08 to a maximum (control) of 0.5 g N_2O-N kg $^{-1}$ fresh yields. The mean N_2OI for the DAP, manure, mixed and control treatments were 0.2 ± 0.1, 0.1 ± 0.0, 0.1 ± 0.0 and 0.4 ± 0.3 respectively (Table 4.7). The N_2OI from the mixed and manure treatments plots were significantly lower compared to that of the control ($p = 0.04$). N_2OI from DAP was similar to those of the other three treatments. The N_2OEI from the experiment ranged from a minimum (mixed) of 0.5 to a maximum (control) of 3.72 g N_2O-N USD^{-1}. N_2OEI from the control was significantly higher ($p = 0.0001$) than that from the other three treatments, which were alike.

Table 4.7**.** Nitrous oxide emission intensity (N_2OI) and nitrous oxide emission economic intensity (N_2OEI) for each treatment

Treatment	N_2OI (g N_2O-N kg^{-1})	N_2OEI (g N_2O-N USD^{-1})
DAP	0.2±0.1ab	1.1±0.3a
Manure	0.1±0.0a	1.0±0.3a
Mixed	0.1±0.0a	0.6±0.0a
Control	0.4±0.3b	3.3±0.6b

Data are the mean of three replicates with standard deviations. Lowercase letters, within columns, indicate significant differences at $p<0.5$. The exchange rate was 1 USD = Ksh 103.85 on 2 January 2017

The lowest mean N_2OEI was from the mixed treatment (0.6 ± 0.0 g N_2O-N USD^{-1}), while those from DAP, manure and the control were 1.1 ± 0.3; 1.0 ± 0.3 and 3.3 ± 0.6 g N_2O-N USD^{-1} respectively (Table 4.7).

4.4 Discussion

Greenhouse gas emission intensity (*i.e.* GHG emissions assessed as a function of crop yield) has become one of the most commonly used metrics for assessing the climate impacts of agricultural practices because it accounts for both negative and positive outcomes from agriculture (Moise et al., 2006; van Groenigen et al., 2010; Linquist et al., 2012). This measure of efficiency, however, ignores the fact that although crop yields often correlate to economic performance, there are times when they do not. Given that economic performance typically drives farmers' decision-making and adoption of agricultural management practices in many circumstances, an indicator of economic efficiency of emissions was developed and applied for the first time in an *in situ* N_2O gas measurement study to represent more effectively the trade-offs between livelihoods and climate change mitigation.

The results from the experiment demonstrate how the choice of indicator could alter the selection of best-fit soil management strategies. When considering N_2O emissions from the four treatments, the highest emissions per unit hectare came from DAP, followed by the mixed treatment, and the lowest from manure and the control. However, after N_2O emissions were expressed as a function of yield (N_2OI), the mixed and manure treatments performed best (*i.e.* had the lowest N_2OI values). It is a different story with N_2OEI, however, because the mixed treatment had the lowest value and so would be the soil fertility management strategy that best optimises economic and environmental performance.

While this is the first study to use N_2OEI in N_2O measurements, other studies have investigated N_2OI in vegetable production. The present findings are 40 % (taking an average of 1.5 from the four treatments) higher than N_2O emission levels (0.9 kg N_2O-N ha^{-1} yr^{-1}) reported from two experimental fields of low-input vegetable production in the rural highlands of Kenya (Rosenstock et al., 2016). Higher emissions from our study may be partly attributed to high clay content in the soil of our experimental plots (Table 4.2) which could contain inherent N supply. However, the present results were approximately 97% and 69% lower than N_2O emissions and average N_2O EF respectively reported from urban vegetable gardens in Niger and Burkina Faso (Predotova et al., 2010; Lompo et al., 2012). The reason for this difference could be the high N application rates (seven times greater) in addition to higher soil moisture (more than double) from the year-round irrigation of urban vegetable gardens.

In general, the present findings are consistent with previous studies that intensification of crop production potentially reduces the intensity of N_2O emission (Nyamadzawo et al., 2014a; Hickman et al., 2014). This is evident by the lower amounts of N_2OEI and N_2OI from the DAP, manure and mixed treatments compared to the control. Nyamadzawo et al. (2014b) reported reduced N_2OI of up to 55% from fertiliser intensification compared to the control with no fertiliser input, which is in agreement with the present results. Lower emission intensity from these three treatments was mainly due to higher margins and yields compared to the control. The higher margins and yields are probably due to improved nitrogen use efficiency in the DAP, manure and mixed treatments compared to the control.

Despite the lack of significant differences in the amount of N_2OEI and N_2OI between the DAP and mixed treatments (possibly due to high inter-plot variability), the mixed treatment yielded the best economic performance with minimum negative environmental impact, reducing N_2OEI and N_2OI by 45.5% and 50% respectively. However, this was associated with 14%, 20.7% and 15% less economic, yield and returns to labour when compared to those of DAP. The manure treatment had the second lowest environmental impact, but was associated with higher economic (67%) and yield (64%) trade-offs. Therefore, sustainable intensification appears to be achieved by applying nitrogen fertilisers from a mix of organic and inorganic sources. However, farmers are likely to opt for DAP since it offers the greatest economic benefits and has lower labour requirements. The forgone economic benefits (14% economic trade-off) of deciding to use nitrogen fertilisers from a mix of organic and inorganic sources needs to be reduced. This may be done by providing farmers price premiums in market places (e.g. supermarkets) for AIV produced with more environmentally sound methods.

This study has shown that intensification can optimise livelihood and climate trade-offs, but these systems still generate emissions. Elevated N_2O emissions were observed, lasting between two and three weeks following N fertilisation and rainfall events. A similar temporal pattern of N_2O emissions has been observed in experimental maize plots and smallholder mixed farming systems in Kenya (Hickman et al., 2014; Pelster et al., 2017). In the present study, N_2O flux rates remained below 15 μg N_2O-N $m^{-2}hr^{-1}$ in all the treatments except in periods following N fertilisation and rainfall events when N_2O flux rates were higher from the DAP and mixed treatments. N_2O is emitted from the soil because of nitrification and denitrification processes occurring in the soil (Mosier et al., 1998; Robertson and Groffman, 2007). Denitrification is an anaerobic microbial process that is strongly regulated by soil moisture and gaseous diffusion (de Klein et al., 2003), and occurs mostly when soil moisture reaches and exceeds the threshold (60%) (Linn and Doran, 1984). Furthermore, denitrification is strongly controlled by the availability of N and increases with rising N availability (Beauchamp, 1997; Castaldi and Smith, 1998). A significant positive correlation was found between N_2O emissions and soil NO_3^-N, NH_4^+-N and WFPS. Therefore, the low N_2O emissions observed could likely be attributed to limited available N and a low soil moisture content during the present study while the temporal fluctuation in the N_2O flux, particularly from the DAP and mixed treatments, is a function of the combined effects of N fertilisation and rainfall events.

The significantly high seasonal cumulative N_2O emissions from the DAP treatment could be the consequence of high available N in the soil. This is reflected in greater concentrations of NO_3-N in soil samples from DAP than from the other three treatments. It is likely that a fraction of this NO_3-N was absorbed by the plant and used for growth, resulting in greater yields from the DAP treatment. However, another fraction may have remained as soil NO_3-N and been converted to N_2O through the denitrification process, which caused the greater cumulative N_2O emission from the DAP treatment.

Initial immobilisation and the delayed release of N, poor quality of the manure and poor storage methods (1.6% N of dry weight) might also have contributed to the low cumulative N_2O emissions from the mixed and manure treatments. Dick et al. (2008) reported reduced N_2O emissions of up to 58% from a mix of urea, manure and phosphate compared to adjacent soils treated with urea from a continuous cereal and cereal/legume rotation in Mali. The authors also attributed this reduction to the initial immobilisation of N due to the low quality of the manure. A low N content in the manure may be due to poor quality feed. Cattle feed in SSA is usually comprised of native pasture and grasses that have low digestibility and a low N content (Rufino et al., 2006; Castellanos-Navarrete et al., 2015). Feed composition and digestibility affect the C/N ratio in the manure, which may in turn affect N_2O emissions (Cardenas et al., 2007).

It is also possible that residual N_2O emissions particularly from manure was not captured during the fallow period (no sampling during fallow period) raising the question whether this resulted to underestimation of cumulative emissions. However, during the fallow period, no or very minimal rainfall was received (Fig. 1). This implies that the soil was dry most of the time, which could largely limit microbial processes and emissions as also reported by Chadwick et al. (2011). Further, N_2O fluxes were measured until they reverted to background emissions in season II and each treatment showed similar temporal pattern as in season I. Also, there was minimal difference between N_2O emissions from season I and II from manure treatment. This suggests that residual N_2O emission that might not have been captured during fallow period is negligible and, hence, does not influence cumulative emissions from manure treatment.

4.5 Conclusion

This study has shown that the inclusion of economic value *versus* just productivity alone may change conclusions around the selection of which soil management practice is the best fit for purpose when wanting to optimise climate and livelihood trade-offs. Although limited in scope, these data provide a first indication of the importance of taking the trade-off analysis one step further to include economic value. It is therefore concluded that soil fertilisation from a mix of organic and inorganic nitrogen fertilisers is a promising agronomic pathway towards achieving optimal combined economic and environmental outcomes from vegetable production in peri-urban Kenya. Future work in this field should consider the limitations of considering productivity alone when trying to reflect the true nature of the trade-offs faced by farmers.

Acknowledgments

This study is part of the Horticultural Innovations and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project funded by the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry of Economic Cooperation and Development (BMZ) within the framework of the GlobE – Global Food Security programme (Ref: FKZ 031A248A). We are also grateful to ICRAF (Nairobi) for allowing us to use their facilities during data collection and laboratory analysis. The authors are equally grateful to the farmer for allowing us to set up the experiment on his farm and for his close collaboration throughout the experimental period. The CGIAR Research Programmes on Climate Change, Agriculture and Food Security (CCAFS)'s Low Emissions Development Flagship supported T. Rosenstock (see www.ccafs.cgiar.org for the donors that support CCAFS).

References

Abukutsa-Onyango, M. P., Kavagi, P. A., & Habwe, F.O. (2010). Iron and protein content of priority African indigenous vegetables in the Lake Victoria Basin. *Journal Agricultural Science and Technology,* 4, 67–69.

Africa Agriculture Status Report. (2016). Progress towards agricultural transformation in Africa. http://reliefweb.int/sites/reliefweb.int/files/resources/assr.pdf, Accessed date: 10 April 2017.

Arias-Navarro, C., Díaz-Pinés, E., Kiese, R., Rosenstock, T. S., Rufino, M. C., Stern, D., & Butterbach-Bahl, K. (2013). Gas pooling: a sampling technique to overcome spatial heterogeneity of soil carbon dioxide and nitrous oxide fluxes. *Soil Biology Biochemistry*, 67, 20–23.

Beauchamp, E.G. (1997). Nitrous oxide emission from agricultural soils. *Canadian Journal of Soil Science*, 77, 113–123.

Butterbach-Bahl, K., Ole Sander, B., Pelster, D., & Díaz-Pinés, E. (2016). Quantifying greenhouse gas emissions from managed and natural soils. In: Rosenstock, S., Rufino, M.C., Butterbach-Bahl, K., Wollenberg, E., Richards, M. (Eds.), Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture. Springer, Switzerland, pp. 71–98.

Cardenas, L.M., Chadwick, D., Scholefield, D., Fychan, R., Marley, C.L., Jones, R., Bol, R., Well, R., & Vallejo, A. (2007). The effect of diet manipulation on nitrous oxide and methane emissions from manure application to incubated grassland soils. *Atmospheric Environment*, 41, 7096–7107.

Castaldi, S., & Smith, K.A. (1998). Effect of cycloheximide on N_2O and NO_3 production in a forest and an agricultural soil. Biology and Fertility of Soils 27, 27–34.

Castellanos-Navarrete, A., Tittonell, P., Rufino, M.C., & Giller, K.E. (2015). Feeding, crop residue and manure management for integrated soil fertility management – a case study from Kenya. *Agriculture Systems*, 134, 24–35.

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B., & Misselbrook, T. (2011). Manure management: implications for greenhouse gas emissions. *Animal Feed Science Technology*, 166–167, 514–531.

Dick, J., Kaya, B., Soutoura, M., Skiba, U., Smith, R., Niang, A., & Tabo, R. (2008). The contribution of agricultural practices to nitrous oxide emissions in semi-arid Mali. *Soil Use Management*, 24 (292–30).

van Groenigen, J.W., Velthof, G.L., Oenema, O., Van Groenigen, K.J., & Van Kessel, C. (2010). Towards an agronomic assessment of N_2O emissions: a case study for arable crops. *European Journal of Soil Science*, 61, 903–913.

Hickman, J.E., Havlikova, M., Kroeze, C., & Palm, C.A. (2011). Current and future nitrous oxide emissions from African agriculture. *Current Opinion in Environmental Sustainability*, 5, 370–378.

Hickman, J. E., Palm, C., Mutuo, P., Melillo, J., & Tang, J. 2014. Nitrous oxide (N_2O) emissions in response to increasing fertilizer addition in maize (Zea mays L.) agriculture in western Kenya. *Nutrient Cycling in Agroecosystems*, 100, 177–187.

Hickman, J.E., Tully, K.L., Groffman, P.M., Diru, W., & Palm, C.A. (2015). A potential tipping point in tropical agriculture: avoiding rapid increases in nitrous oxide fluxes from agricultural intensification in Kenya. *Journal of Geophysical Research*, 12, 938–951.

IFDC, 2006. Agricultural production and soil nutrient mining in Africa. http://www.newscientist.com/article/dn8929-soil-health-crisis-threatens-africas-food-supply.html, Accessed date: 20 February 2017.

Kim, D., Thomas, D.A., Pelster, D., Rosenstock, S.T., & Sanz-Cobena, A. (2016). Greenhouse gas emissions from natural ecosystems and agricultural lands in sub-Saharan Africa: synthesis of available data and suggestions for further research. *Biogeosciences*, 13, 4789–4809.

Kimetu, J. M., Mugendi, D. N., Bationo, A., Palm, C. A., Mutuo, P. K., Kihara, J., Nandwa, S., & Giller, K. (2006). Partial balance of nitrogen in a maize cropping system in humic nitisol of Central Kenya. *Nutrient Cycling in Agroecosystems,* 76, 261–270.

de Klein, C. M., Barton, L., Sherlock, R. R., Li, Z., & Littlejohn, R. P. (2003). Estimating a nitrous oxide emission factor for animal urine from New Zealand pastoral soils. *Australian Journal of Soil Research*, 41, 381–399.

Linn, D. M., & Doran, J. W. (1984). Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. *Soil Science Society of America Journal*, 48, 1267–1272.

Linquist, B., van Groenigen, K.J., Adviento-Borbe, M.A., Pittelkow, C., & van Kessel, C., (2012). An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology*, 18, 194–209.

Lompo, D.J., Sangaré, S.A., Compaoré, E., Sadego, P.M., Predotova, M., & Schlecht, E., Buerkert, A. (2012). Gaseous emissions of nitrogen and carbon from urban vegetable gardens in Bobo-Dioulasso, Burkina Faso. Journal of Plant Nutrition and Soil Science, 175, 846–853.

Mosier, A.R., Delgado, J.A., & Keller, M. (1998). Methane and nitrous oxide fluxes in an acid oxisol in western Puerto Rico: effects of tillage, liming and fertilization. Soil Biol. Biochem. 30, 2087–2098. Mosier, A.R., Halvorson, A.D., Reule, C.A., Liu, X.J., 2006. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in north-eastern Colorado. *Journal of Environmental Quality*, 35, 1584–1598.

Ngugi, I.K., Gitau, R., & Nyoro, J. (2007). Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya, re-governing Markets Innovative Practice Series IIED London.

Nyamadzawo, G., Wuta, M., Nyamangara, J., Smith, J. L., & Rees, R. M. (2014a). Nitrous oxide and methane emissions from cultivated seasonal wetland (dambo) soils with inorganic, organic and integrated nutrient management. *Nutrient Cycling in Agroecosystems*, 100 (2), 161–175.

Nyamadzawo, G., Shi, Y., Chirinda, N., Olesen, J.R., Mapanda, F., Wuta, M., Wu, W., Meng, F., Oelofse, M., de Neergaard, A., & Smith, J. (2014b). Combining organic and inorganic nitrogen fertilization reduces N_2O emissions from cereal crops: a comparative analysis of China and Zimbabwe. *Mitigation and Adaptation Strategies for Global Change*, 1–13.

Okalebo, R., Gathua, K.W., & Woomer, P.L. (2002). Laboratory methods of soil and plant analysis: a working manual. In: Tropical Soil Biology and Fertility. Soil Science Society of East Africa.

Okello, J. J., Largerkvist, C. J., Ngigi, M. W., Karanja, N. (2014). Means-end chain analysis explains soil fertility management decisions by peri-urban vegetable growers in Kenya. *International Journal of Agricultural Sustainability*, 12 (2), 183–199.

Parkin, T. B., & Venterea, R. T. (2010). Sampling Protocols. In: Follett, R.F. (Ed.), Chamber based Trace Gas Flux Measurements and Sampling Protocols. Department of Agriculture, U.S. www.ars.usda.gov/research/GRACEnet, Accessed date: 20 September 2017.

Pelster, D., Rufino, M., Rosenstock, T., Mango, J., Gustavo, Saiz, Eugenio, D., Baldi, G., & Butterbach-Bahl, K. (2017). Smallholder farms in eastern African tropical highlands have low soil greenhouse gas flux. *Biogeosciences,* 14, 87–202.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience*, 55 (7), 573–582.

Predotova, M., Gebauer, J., Diogo, R. V., Schlecht, E., & Buerkert, A. (2010). Emissions of ammonia, nitrous oxide and carbon dioxide from urban gardens in Niamey, Niger. *Field Crop Research*, 115, 1–8.

Rashti, R. M., Wang, W., Moody, P., Chen, C., & Ghadiri, H. (2015). Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: a review. *Atmospheric Environment*, 112, 225–233.

Robertson, G. P., & Groffman, P. M. (2007). Nitrogen transformation. In: Paul, E.A. (Eds.), Soil Microbiology, Biochemistry and Ecology. Springer, New York, USA, pp. 341–364.

Rosenstock, T.S., Mathew, M., Pelster, D.E., Butterbach-Bahl, K., Rufino, M.C., Thiong'o, M., Mutuo, P., Abwanda, S., Rioux, J., Kimaro, A.A., Neufeldt, H., 2016. Greenhouse gas fluxes from agricultural soils of Kenya and Tanzania. *Journal of Geophysphical Research*, 121, 1568–1580.

Rufino, M. C., Rowe, E.C., Delve, R. J., & Giller, K. E. (2006). Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. *Agriculture, Ecosystems, and Environment*, 112 (4), 261–282.

Shackleton, M. C., Pasquini, M. W., Dresher, W. A. (2009). African Indigenous Vegetables in Urban Agriculture. Earthscan Publishers, London, pp. 1–339.

Shcherbak, I., Millar, N., & Robertson, G. P. (2014). Global meta-analysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen. *Proceedings of National Academy of Science, U. S. A.*, 111 (25), 9199–9204.

Syakila, A., & Kroeze, C. (2011). The global nitrous oxide budget revisited. *GHG Measurement and Management*, 1, 17–26.

Tilman, D., & Clark, M., (2014). Global diets link environmental sustainability and human health. *Nature*, 515 (7528), 518–522.

Tully, K. L., Abwanda, S., Thiong'o, M., Mutuo, P. M., & Rosenstock, T., (2017). Nitrous oxide and methane fluxes from urine and dung deposited on Kenyan pastures. *Journal of Environmental Quality,* 46 (4), 921–929.

Chapter 5

General discussion

5.1 Introduction

African indigenous vegetables (AIV) have gained greater recognition across SSA in the recent past because of increased awareness on their nutritional value and health benefits (Vorster et al., 2007; Yang and Keding, 2009). This rising consumer consciousness has caused an increase in demand for consumption of AIVs, which in turn has triggered intensification of AIV production. For instance, land area allocated for AIV cultivation in Kenya increased by 31%, rising from 27,102 ha in 2009 to 35,503 ha in 2014 (HCDA 2014). In addition, yields and AIV value increased by 6% and 10% respectively, in 2014 compared to what was obtained in 2012 (HCDA 2014). Despite this upward trend of AIV production, the current supply does not match the market demand particularly during dry season production periods (Ngugi et al., 2007). This is partly because of increasing water scarcity (i.e. due to increased water demand from different competing water users and increased dry spells) to support year round AIV production, limited arable land for expansion, low soil fertility and lack of good quality seeds (Ngugi et al., 2007; Onium and Manikin, 2008, Abukusta et al., 2010). The growing and increasingly affluent population and rising urbanisation are expected to further stimulate demand for consumption of AIVs, which is likely to widen the supply deficit if the avenue of sustainable intensification of AIV is not consistently pursued. This study therefore, focused on the potential pathways to promote SI of smallholder AIV production in Kenya. In order to achieve this goal, the study: (1) evaluated the extent and underlying factors influencing the adoption of SIPs, (2) examined the impacts of SIP adoption on farmers' livelihoods, and (3) assessed economic performance and ecological outcomes of soil fertilisation strategies in order to recommend soil fertility management strategies, which optimises production, livelihood and climate trade-offs. This study was carried out in four Kenyan counties: two each from rural and peri-urban areas. It is important to note here that the data obtained from these four counties is not representative at national level. However, data do provide a comprehensive overview of AIV production in rural and peri-urban areas. Therefore, the findings can be generalized to AIV production in rural and peri-urban areas of Kenya. This chapter therefore presents the methodological approaches that were used and provides the main findings that were obtained. Finally, the chapter concludes by giving practical implications and research areas for future considerations.

5.2 Methodological approaches

5.2.1. Sampling design and data collection

This thesis was conducted within the framework of the HORTINLEA research project, which was interdisciplinary in nature and aimed at addressing food security challenges through diversifying food systems in East Africa. The project was divided into 14 subprojects based on different thematic research areas while maintaining close collaboration between them. Based on this collaboration, the first and the second objectives of this thesis used primary data from the HORTINLEA household panel survey carried out in Kenya between September and November 2016. The survey captured AIV production and marketing data for the 2015/2016 production season. Six hundred and eighty-five farming households were selected using a multi-stage sampling technique. In the first stage of the sampling procedure, two production systems were selected based on their AIV production potential: rural and peri-urban (GoK, 2014). Secondly, two counties were further selected from each production system: Kakamega and Kisii from rural areas and Kiambu and Nakuru from peri-urban areas. In the next step, five to ten divisions were randomly selected from each county depending on the intensity of AIV production and the size of division. Finally, a proportionate to the size sampling approach (according to village household size) was used to select farming households at village level. Each household was then given a structured questionnaire to characterise the household socioeconomic status and production of AIV, including management practices such as adoption of SIPs (integrated soil fertility management, use of organic manure, improved irrigation systems and AIV diversification) and marketing data. Complementary data were also collected on assets, land and livestock ownership, income sources, access to credit and extension services, social networks and farmers' willingness to take production risks (based on farmers' perception).

5.2.2 On-farm trials

Given the nature of the third objective, an on-farm experiment was established in Wangige, Kiambu County, on a site that is representative of peri-urban smallholder AIV production in the area to measure N_2O emissions. The experiment spanned two growing seasons: short rains in 2015 (season I) and long rains in 2016 (season II). The details of the experimental design, treatments, the used N_2O sampling techniques, yield measurement and estimation of economic performances from each treatment (soil fertility management) are found in the methodology section of Chapter 4. Manure and integrated soil fertilisation, also referred in Chapter 4 as mixed (combined use of DAP and manure) fertilisation were taken as SIPs (also evaluated in Chapter 2 and 3) while, DAP was considered a rather "unsustainable" fertilisation strategy. This is because continuous use of chemical fertilisers such as DAP without concurrent steps taken to raise soil pH has been reported to cause soil acidification problems (Obura et al., 2010). Acidic soils lock up phosphorous in the soil and prevent it from being available to the plant, thereby depressing crop response to nitrogen application (Burke, 2013; Obura et al., 2010).

5.3 Data analysis methods

5.3.1 Multivariate probit (MVP) model

Inferential analysis using (chi-square test) was used to test for significant difference on the extent of adoption of SIPs between rural and peri-urban areas. SIP adoption intensities were determined by counting the number of SIP adopted by each farming household. Furthermore, a MVP model was employed to determine factors influencing farmers' decisions to select any of the four SIPs considered. MVP model was chosen because of its ability to model simultaneous multiple adoption decisions in the presence of adoption interdependence. Further, the model allows for the calculation of the correlation between unobserved disturbances terms in the selection equations, and the relationships between the selections of different adoption options (Hausman and Wise, 1978). It also permits the simultaneous modelling of a set of independent variables on each of the different adoption options (the four SIPs), while allowing the unobserved or the error terms to be freely correlated (Madalla, 1986; Wooldridge, 2010). This MVP model has been employed in previous studies to model adopting of SIPs in smallholder cereal crop production in SSA countries such as Kenya, Ethiopia and Malawi (Kassie et al., 2013; Teklewold et al., 2013; Kassie et al., 2015; Ndiritu et al., 2014).

5.3.2 Treatment effect model

A treatment effect model was used in Chapter 3 to evaluate the impacts of adoption on SIPs on household income (proxy indicator for household livelihood). The model was chosen because of its ability to directly estimate impacts of adoption on household income while at the same time addressing the problem of sample selection bias as well accounting for both observed and unobserved variables (Cong and Drunker, 2001). Other methods such as propensity score matching (PSM) do not account for unobserved variables such as farmer's motivation and skills. The PSM method assumes that impacts of adoption of SIPs is only driven by farmer observable characteristics (Heckman et al., 1997; Dehejia and Wahba, 2002). The endogenous switching regression (ERS) model accounts for self-selection bias, as well as both observable and unobservable variables, but lacks the power to directly estimate the impacts (Lokshin and Sajaia, 2004). The ERS model was therefore, used together with the treatment effect model to check the robustness of the results. Three SIPs, improved irrigation systems, use of organic manure and integrated soil fertility management were considered in Chapter 3. Thus, adopters were taken as those farming households who practised at least one of the three

SIPs. Diversification of AIV was left out of the analysis because in Chapter 2, the number of households who adopted this practise was high (83%). Given that adopters were considered as those farming households who adopted at least one of the three SIPs, the inclusion of AIV diversification would have significantly reduced the number of non-adopters. Total household income and crop income were used as proxy indicators to assess farmers' livelihoods.

5.3.3 N_2O emission, economic performance, livelihood and climate trade-off analysis

In order to evaluate N_2O emissions of various soil fertilisation strategies, cumulative estimates of N_2O emission were assessed for each treatment for each season and the entire experimental period. Cumulative N_2O emission estimates were based on the mean flux of the three chambers from each plot and linear interpolation between sampling events using the trapezoidal rule. Gross margin (GM) analysis was used to evaluate economic performance of each treatment, i.e. each soil fertilisation strategy, and was calculated as gross production value minus the variable production costs. An adapted benefit-cost ratio (BCR) was estimated by dividing GM by the total variable cost. N_2OI was calculated by dividing seasonal cumulative N_2O emission for each treatment by the corresponding total fresh vegetable yields of both seasons. Furthermore, a new metric indicator, nitrous oxide economic emission intensity (N_2OEI), was developed and applied for the first time *in situ* N_2O gas measurements study to represent more effectively the trade-offs between livelihoods and environmental protection. This is because existing greenhouse gas emissions intensities (i.e. GHG emissions assessed as a function of crop yield) a commonly used metric for assessing environmental or climate impacts of agricultural practices ignores that fact that although crop yields often correlates with economic performance, there are times when they do not. Similar to N_2OI, N_2OEI was determined in this study by dividing cumulative N_2O emissions for each treatment by the corresponding cumulative GM. Analysis of variance (ANOVA) was used to test for significant differences between the effects of the different treatments on N_2O emission ha^{-1}, seasonal and total vegetable yields, GM, N_2OI and N_2OEI.

5.4 Empirical findings

5.4.1. The extent, intensity and factors influencing adoption of SIPs

The focus of Chapter 2 was to assess the extent and adoption intensities of SIPs in rural and peri-urban AIV production in Kenya. Furthermore, it identifies complementarities and substitutabilities between SIPs, and factors influencing adoption decisions. The four SIPs under evaluation were improved irrigation systems, organic manure, integrated soil fertility management and AIV diversification. The major findings of this chapter (summarised in table

5.1) revealed that use of organic manure and AIV diversification were widely adopted across rural and peri-urban production areas. In contrast related to farm location, the extent of AIV diversification was significantly higher in rural compared to peri-urban areas. Generally, improved irrigation systems and integrated soil fertility management were rather rarely adopted (<13%) in both rural and peri-urban settings. However, the majority of those who used improved irrigation systems and integrated soil fertility management were mostly from peri-urban areas. With regard to adoption intensity, most farmers simultaneously adopted two SIPs with no difference between the rural and peri-urban production environments.

Table 5.1. Summary of the extent and adoption intensity of the four SIPs in AIV production

Level of adoption[a]		Adoption intensities[b]		
High	Low	Overall	High (>2 SIPs)	Low(≤2 SIPs)
Animal manure	Improved irrigation systems	2	Peri-urban	Rural
AIV diversification	Integrated soil fertility management	-	-	-

[a] indicates the overall extent of adoption from all 685 smallholder AIV producers
[b] indicates the number of SIPs adopted by majority of the household in rural and peri-urban AIV production.

On the other hand, the majority of adopters of three SIPs were from peri-urban areas, suggesting that adoption intensity of SIPs is slightly higher in peri-urban than rural areas. Moreover, complementarities and substitutabilities between SIPs were also identified For instance, table 2.4 indicates that improved irrigation systems and integrated soil fertility management as well as AIV diversification and organic manure can be adopted jointly because they complement each other. On the contrary, the use of integrated soil fertility management and AIV diversification, and the use of organic manure and integrated soil fertility management substitute one another. Complementarities and substitutabilities between SIPs may have policy implications in that a change in a policy affecting a single SIP might have a spill over effect on other SIPs. Therefore, it is important for policy makers to consider such possibility of complementarities and substitutabilities when formulating policies to promote SI of AIV production.

The findings of determinants (table 2.5) of adoption decisions revealed that market integration strongly influences adoption of all the four SIPs. For example, farmers who sell AIVs to informal markets significantly adopted improved irrigation systems, organic manure use and diversifying AIV production. Those selling to formal market outlets were also more likely to adopt integrated soil fertility management, but refrained from solely using manure. Higher household income also significantly influenced adoption of improved irrigation systems, organic manure and AIV diversification. This result highlights the importance of cash in the early stages of adoption decision (i.e. cash is needed to purchase irrigation equipment, drill wells and pay for labour). A peri-urban AIV production environment positively influenced adoption of improved irrigation systems and the use of integrated soil fertility management. This was attributed to the fact that peri-urban farmers have better access to good infrastructure (particularly transport and communications) which enables farmers to access farm inputs, information on new agricultural technologies and lucrative urban market outlets at reduced transaction costs than their counterparts in rural areas. In addition, those farming households with higher education level, own land and belong to a farmer group were more likely to use animal manure. There is also a clear link between access to information on new agricultural technologies and adoption of integrated soil fertility management. Further, male headed farm households and those households with farming as their main occupation were more likely to use improved irrigation systems.

5.4.2. Impacts on household income

With the increased understanding of the level and determinants of adoption of SIPs in AIV production from Chapter 2, Chapter 3 took a step further, to evaluate its resulting impact on farmers' livelihoods. The total household income from farm and off-farm activities was taken as proxy-indicator for livelihood. The impact analysis is an important and critical step given that increasing farm income is one of the major components of the goal of SI (Pretty et al., 2011). In addition, it was demonstrated in Chapter 2 that household income strongly influenced adoption decisions for improved irrigation systems, organic manure and AIV diversification. This implies that SIPs have to be eventually profitable to the farmers in order to sustainably increase their uptake. It was assumed (null hypothesis) that there is no significant difference between household income of adopters and non-adopters. The results from the treatment effect model revealed that adoption of SIPs significantly increases both incomes with marginal effects of 1.2 and 0.9, respectively (table 3.3). These marginal effects translates to 14.8% and 9.6% increase in crop and total household income, respectively using the sample mean values of crop and total household income in table 3.1. For robustness check, impacts of adoption on crop and total household income were also evaluated using ESR model, even though the results were not reported because of space limitation, but are available on request. Only estimates of average treatment effects on the treated (ATT) are therefore, presented in table 3.5. These estimates demonstrate that adoption of SIP increases crop and total household income by 53.2% and 12.85% respectively. Overall, these findings imply that the adoption of

SIPs should be encouraged because it improves household income. Chapter 3 also assessed households' socio-economic, institutional and assets access related factors, in order to capture differential impacts of adoption on crop and total household income. The findings from this assessment are presented and discussed in table 3.4 in Chapter 3 respectively. In summary, these results revealed that education level, gender, land size, livestock ownership, land fertility, access to credit and information regarding new agricultural technologies and innovations positive affects one or both incomes.

5.4.3. Impacts on the environment (N_2O emission, economic performance and trade-offs)

Increasing crop productivity per unit land area while protecting the environment (i.e. reducing GHG emissions) is another important component of SI goal (The Royal Society, 2009; Godfray et al., 2010). Chapter 4 therefore, presents N_2O emission and economic performance of three soil fertilisation strategies (treatments) and a no nitrogen input–control. The soil fertility strategies evaluated were use of manure, mixed (also referred to integrated soil fertilisation) and inorganic fertilisers (DAP). The results of cumulative N_2O emissions and emission factors from each soil fertility management are presented in table 4.3. It is evident from these results that emissions from the DAP treatment were significantly higher than those from the three other treatments, which were similar to one another. In addition, emission factors for DAP and mixed treatments were 2.6% and 0.7% respectively, while manure treatment had zero. The significantly higher cumulative N_2O emissions from DAP treatment could be attributed high available N in the soil since DAP had high concentration of NO_3-N in the soil. It is likely that part of this available N was used for plant growth while the remainder was converted to N_2O through denitrification process leading to more emissions. Initial immobilisation and delayed release of N, poor quality of manure (6% N of dry weight) and poor storage methods might have contributed to low emissions from manure and mixed integrated soil fertility management. Dick et al. (2008) found reduced N_2O emissions of up to 58% from a mix of urea, manure and phosphate compared to adjacent soils treated with urea in Mali.

The effects of each treatment on the yields of African nightshade and economic performance are shown in table 4.4 and 4.5 respectively. Yields from DAP and mixed were significantly higher than those from manure and control, which were similar to one another. Fertilisation from DAP showed the best economic performance in terms of GM, land and labour productivity. In general, the GM from the four soil fertility management varied from 2707.8 to 290.1 USD ha^{-1}, while BCR ranged from 4.6 to 1.7. Net income per labour hour varied from 3.9 to 0.5 USD per labour hour. No N-input plots (control) showed the lowest economic performance. GM, BCR and net income per labour hour from DAP and mixed treatments were similar, but significantly higher than those from manure and control. The most labour intensive soil fertility strategy was the use of manure with labour input of 736 working hours' ha^{-1}.

Table 4.7 presents the findings of N_2O emission intensities based on crop productivity and economic efficiency, which are then further discussed in the respective section in Chapter 4. In brief, the mean N_2OI from the no N-input (control) was the highest followed by DAP, indicating that both strategies, the least intense and the one with highest N input were the least climate-smart fertilisation strategies. Manure and mixed fertilisation had significantly lower N_2OI compared to that of control. N_2OEI from the control was significantly higher (3.3 ± 0.6 N_2O-N USD^{-1}) than those from the other three treatments, which were alike. The lowest N_2OEI was from mixed treatment (0.6 ± 0.0 N_2O-N USD^{-1}), while those from DAP and manure were 1.1 ± 0.3; 1.0 ± 0.3 N_2O-N USD^{-1} respectively. In general, these results demonstrate how a choice of indicator (metric) could alter the selection of best-fit soil fertilisation strategies. For instance, when considering N_2O emissions, the highest emissions per unit land area came from DAP, followed by mixed, and lowest from manure and control. However, after N_2O emissions were expressed as a function of yield, mixed and manure treatments performed best (lowest environmental impact, i.e. had lowest N_2OI values). With N_2OEI, however, a different story comes up, mixed treatment had the lowest value. These results suggest that mixed or integrated soil fertility manage strategy optimises economic and environmental performance. Therefore, the conclusions on the selection of which soil management practice is the best fit for achieving the goal of SI (i.e. optimise livelihood and climate trade-offs) may differ depending on the metrics chosen.

5.5 Limitation of the study

This research had some limitations, as is the case with most of the empirical studies, which needs to be highlighted before giving the practical and policy implications of the findings. First, this study was carried out only in four Kenyan counties implying that data obtained was not representative at national level. Two, most of the farmers interviewed in Kakamega were already from established farmer groups, which potentially may lead to some level of biasness when interpreting effect of social capital (groups) on adoption of SIPs. Thirdly, evaluation of causal effect of adoption of SIPs on farmers' livelihoods only focused on two livelihoods indicators (crop income and total household income). Inclusion of additional livelihood/ welfare indicators such as asset and consumption scores and where feasible income from single AIV could give more robust and in-depth understanding of impacts of adoption on farmers livelihoods. Finally, an on-farm trial was carried out in one location (peri-urban area in Kiambu County- due to limited funds), which has specific climate and soil attributes that may differ from other AIV production areas such as Kakamega and Kisii. The differences in climate and soil characteristics potentially affects N_2O emissions profiles, which in turn might alter N_2OEI levels as well as livelihood and climate trade-offs. More on-farm trials established on famers' fields both in rural and peri-urban AIV production areas could provide more robust data that allows in-depth analysis of livelihood and climate trade-offs from soil fertility management strategies. Nonetheless, the findings of this study widens our general knowledge on the scale and underlying factors influencing adoption of SIPs in AIV production in rural and peri-urban areas. In addition, it provides a general indication of the impacts adoption of SIPs on farmers' livelihoods as well as soil fertility management strategy that optimizes livelihood and climate trade-offs in AIV production. Therefore, these findings have the following practical and policy implications that aims to promote sustainable intensification of smallholder AIV production in Kenya.

5.6 Practical implications of the findings

5.6.1 Building smallholder financial capital base

Stakeholders actively involved in as well as programs aiming at promoting increased uptake of SIPs in AIV production should focus on building smallholder ability to accumulate more financial capital. This is of utmost importance because as outlined in Chapter 2 household income was identified as one significant factor conditioning adoption of improved irrigation systems, organic manure and AIV diversification. This is because the aforementioned SIPs e.g. improved irrigation systems are capital intensive, hence the need for more household capital base. Building household financial capital base can be done through increasing productivity of current agricultural land holding by investing on soil management strategies that improves soil fertility. This is important because 63% of the farmers across all counties indicated that they were grappling with soil fertility problems on AIV land. In addition, improved access to credit services plays a critical role especially in acquiring relevant production resources (i.e. improved irrigation facilities) as well as seed capital to start and run farm enterprise(s) that generates more household income (Croft et al., 2016). Moreover, part of the credit could be used to finance periodic soil testing in order to better inform farmers on the amount of soil nutrient input required for optimal AIV production and to avoid soil degradation. Such periodic tests should also include manure samples to help in determining nitrogen amount contained in the manure and how much to add in case of deficit. Therefore, county governments and other development agencies (e.g. non-governmental organizations) should partner with financial institutions in helping more AIV farmers to access credit services (only 24% accessed credit) so as to facilitate expansion of their financial capital as was indicated in Chapter 3. This can be done by linking more farmers to credit providers, such as table banking[9] and mobile phone-base credit access platforms. These credit providers should be encouraged to develop and offer "*special restrict credits*" with cross-compliance policies that require farmers to use obtained credit only for investment on sustainable land management and AIV production. Further, investing on more targeted farmers' education and training programs such as best AIV agronomic practices and skills (e.g. simple own farm soil fertility testing skills), and financial literacy may help famers to properly manage credit obtained thus increasing chances of earning more returns from their investment. These trainings, particularly on financial literacy, are crucial given that farmers' average education was primary level (8 years of schooling).

5.6.2 More integration of producers to effective AIV markets

The results in Chapter 2 showed a positive and significant influence of market integration on the adoption of all the four SIPs. This calls for the need to link more farmers to functional rural and urban AIV markets. This study revealed that 60% of households sell their AIV produce through informal market outlets while only one third access formal markets. This can be achieved for example, by organizing farmers into AIV producer groups, which helps them to negotiate for new and already existing AIV markets with fair and enforceable contractual terms. Market integration encourages farmers to transform their subsistence AIV production into market/commercial oriented production, which has more benefits on farmers' livelihood (Shiferaw et al., 2007). This will in turn, make investment on those SIPs that are hardly disseminated (e.g. improved irrigation systems and integrated soil fertility management which had low adoption levels - >13%) more profitable thus enhancing more adoption. At policy or government decision level, there is need for increased investment in development of good transport network. This can be done through increasing national and county governments' budgetary allocation for development of new roads and maintenance of existing

[9] A group funding strategy where members of a particular group meet once every month, place their savings, loan repayments and other contributions on the table then borrow immediately either as long term or short term loans to one or a number of interested members.

ones particularly in rural areas. This will open up rural areas making it possible for AIV producers to access market and credits service more easily with low transaction cost, thus increasing livelihood gains from their investment. Improved transport (road) network has been cited in literature as an important factor which enables farmers to access input and out-put markets, and credit services with minimal transaction cost as well as reducing post-harvest losses (AGRA, 2016).

5.6.3 Improved access to power connectivity and water management

The variable representing peri-urban (farm location) was found to positively influence adoption of improved irrigation systems and integrated soil fertility management in Chapter 2. Peri-urban areas of Kenya are characterised by improved infrastructural development (i.e. road network, electricity, communication, urban lucrative markets, and credit services) compared to rural parts. This infrastructural gap in rural areas is the most likely reason to explain the significantly lower adoption of improved irrigation systems and integrated soil fertility management observed in this study. The need for increased investment in infrastructural development (roads and financial institution) is tied with other recommendations needed to foster increased market integration in section 5.5.2. Access to power (electricity, solar energy or other forms of energy) is key factor necessary for adoption of improved irrigation systems. This is because improved irrigations systems rely mostly on electric power in driving motorized pumps, which pump water from wells and other water storages facilities to vegetable fields. Therefore, there is need for increased power connectivity to households. This may be achieved by increasing national budget (funds) allocation for rural electrification program, which is run by the national government. County governments could also help to establish partnership between them, farmers and private organizations such as SunCulture, which deals with the supply and installation of solar powered irrigation systems (SPIS). Such partnership for example should revolve around helping farmers to acquire SIPS by shared cost between county government and the farmer while SunCulture provides free installation and training services (i.e. how to operate and carry out periodic maintenance). Increased access to SPIS is likely to reduce the use of electric or diesel-driven motorized irrigation pumps, which pollutes the environment. In addition, SPIS frees farmers' from over reliance of electricity and fossil fuels (which are often costly and prices fluctuate depending on international market prices) thus increases economic benefits and reduces environment impact (Chandel et al., 2015).

Adequate and stable water supply particularly during dry period is a major input requirement for irrigation. This raises the need to encourage farmers to practice water harvesting (e.g. rainwater) and conservation. Encouraging farmers to buy water-harvesting tanks in groups for example can help them in negotiating better prices. Additionally, agricultural extension officers and NGOs could train farmers on simple and efficient water conservation methods, which make use of locally available technologies. Further, if technically feasible, county governments should consider drilling shared communal boreholes and channelling water to strategic water collection points easily accessible for farmers. This water could then be used as supplementary water supply for irrigation only during extreme water shortage especially in rural areas where farmers sometime have to walk long distance to fetch water.

5.6.4 Dissemination of information on new agricultural technologies and innovation

Key to SI is providing farmers with knowledge, training and incentives that they need to put SI in to practice (Cook et al., 2015). In Chapter 2, this study confirms that access to information regarding new agricultural technologies and innovations is a relevant factor for the adoption of integrated soil fertility management. Chapter 3 also reveals that adoption of integrated soil fertility management increases the probability of generation more income from crops. In addition, Chapter 4 also demonstrated that integrated soil fertilization optimizes livelihood and climate trade-offs. These findings implies that access to information on new agricultural technologies and innovations (e.g. benefits of practicing integrated soil fertility management) can be a major driver to sustainably intensify AIV production in Kenya. Therefore, there is need for stakeholders to intensify dissemination efforts and awareness on the existence and benefits of new agricultural technologies and innovations (e.g. integrated soil fertility management) with more emphasis in rural areas. This is important given that descriptive data shows that only 38% the farming household access this vital information. Such dissemination efforts should include appropriate handling and storage technologies of inputs such as manure to help avoid nutrient losses. The low nitrogen content (1.6% N of dry weight) determined from manure sample in Chapter 4, was partly attributed to poor storage techniques used (e.g. heaping manure outside with no cover) by the farmers. Furthermore, dissemination programs should also consider promoting adoption of SIPs, which complement each (chapter 2) as a package, because partial adoption of single practice may not achieve maximum desired SI goal (increased productivity and environmental outcomes). These dissemination programs can be channel through established farmer groups, local radio stations, development of brochures, agricultural extension officers and as well as farmer field schools/days. In addition, dissemination can also be channel through organizations such as Academic Model Promoting

Access to Health Care (AMPATH) centers which have already established networks of farmers in western Kenya cultivating AIVs to help in combating chronic nutritional deficiency among vulnerable groups (poorest and patients suffering from HIV and other related diseases). Further, development of internet-based AIV mobile E- platform could be another potential avenue for dissemination.

5.6.5 Inclusion of indicator for economic efficiency of emissions in evaluating environmental component of SI goal.

Increasing crop productivity per unit land area while protecting the environment (i.e. reducing GHG emissions) are two important components of SI goal (The Royal Society, 2009; Godfray et al., 2010). Many researchers and more often use greenhouse gas emission intensity (*i.e.* GHG emissions assessed as a function of crop yield) to evaluate environmental or climate impacts of agricultural practices, because it accounts for both negative and positive outcomes from agriculture (Moise et al., 2006; van Groenigen et al., 2010; Linquist et al., 2012). However, this measure of efficiency ignores the fact that although crop yields often correlate to economic performance, there are times when they do not. Therefore, there is need for various proponents of SI to also consider an indicator for economic efficiency of emissions intensity to better guide the evaluation of productivity and environmental goals of SI. For instance, Chapter 4 of this study demonstrated that inclusion of economic value versus just productivity alone may change conclusions around the selection of which soil fertility management practice is the best fit for purpose of achieving the goal of SI (i.e. optimise livelihood and climate trade-offs). This shift to include economic efficiency intensity of emissions is necessary given that smallholder production objective(s) (e.g. farm decision making, resource investments and labour allocation) are more often driven by economic benefits. In addition, inclusion of indicator for economic efficiency helps to directly estimate the forgone economic benefits for environmental protection (reducing GHG emission). This in turn is likely to trigger the debate among policy makers, researchers and other actors working on SI of agro-food systems on who will pay or how to compensate the forgone opportunity cost of environmental protection in the context of smallholder farmer whose primary objective is economic benefits and food security. The case in point is who pays for the 14% economic trade-off for choosing integrated soil fertility management instead of inorganic fertiliser in AIV production?

5.7 Conclusion and future studies

This thesis sought to understand (1) the extent and factors influencing adoption of SIPs, (2) causal effects of adoption of SIPs on farmers' livelihoods, and (3) economic performance and environmental outcomes of soil fertilisations strategies in order to recommend soil fertilization strategy, which optimizes livelihood and climate trade-offs. The findings have shown that the adoption of organic manure and AIV diversification is widespread both in rural and peri-urban areas. However, the extent of adoption of improved irrigation systems and integrated soil fertility management are quite low and even significantly lower in rural areas when compared to peri-urban. Moreover, complementarities and substitutabilities between the four SIPs were also identified. Further, market integration, farm location and household income were the major factors heavily influencing the adoption of most SIPs. With regard to impacts, adoption of SIPs increased crop income and total household income by 53.3% and 12.6% respectively. Furthermore, education level, gender, land size, land fertility, access to credit and information regarding new agricultural technologies and innovations positively affects one or both incomes. Finally, results from on-farm trials shows that DAP alone resulted in at least 14% greater yields, gross margin and returns to labour in absolute terms but had the highest emissions. Productivity climate trade-offs, expressed as N_2OI, were statistically similar for DAP and mixed treatments. However, livelihood and climate trade-offs was minimized under mixed management while maintaining productivity and gross margins. Therefore integrated soil fertilisation is a promising agronomic pathway towards achieving optimal combined economic and environmental outcomes from vegetable production in peri-urban Kenya. The findings of determinants of SIP adoption in Chapter 2 of this thesis highlights the need to: build smallholder financial base, link AIV producers to effective and efficient AIV markets, improved household power connectivity and water management, and increased efforts to disseminate information on availability and benefits of new agricultural technologies and innovation. Moreover, there is need for various proponents of SI to also consider an indicator for economic efficiency of emissions intensity to better evaluate productivity and environmental goals of SI. These recommendations should be gradually implemented, given that some requires substantial budget allocations and new policy framework.

This study recommends further research to determine whether there is any dynamics (i.e. rates of adoption and disadoption) on the extent of adoption of SIPs across a time interval and factors driving the changes if any. In addition, rigorous analysis that utilizes better methods and data sets (e.g. panel data methods which captures time dimension) are needed to better improve our understanding on the impacts of adoption SIPs on farmers' livelihoods. Moreover, it is important to evaluate whether there is any gender difference on adoption of SIPs in AIV production in rural and peri-urban environments. Finally, there is need to consider development of an additional indicator for nutritional efficiency of emissions intensity to capture nutritional and environmental outcomes of SI of AIV production. This is important given that nutritional and health benefits of AIVs have been widely acknowledged. Therefore, determining nutritional efficiency of emissions intensity from SI of AIVs could better help understand how SI of AIV production contributes to sustainable food systems perspectives.

References

Abukutsa, O. M. O. (2010). African indigenous vegetables in Kenya: Strategic repositioning in the horticultural sector. Inaugural Lecture, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya. 30th April

Alliance for a Green Revolution in Africa (AGRA) (2016). *Africa Agriculture Status Report: Progress towards agricultural transformation in Africa*. http://reliefweb.int/sites/reliefweb.int/files/resources/assr.pdf, Accessed date: 26th January 2018.

Burke, W., (2013). Maize production in Zambia and regional marketing: input productivity and output price transmission. PhD dissertation, Michigan State University, East Lansing.

Chandel, S. S., Nagaraju Naik, M., & Chandel, R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. *Renewable and Sustainable Energy Reviews, 49*, 1084-1099. doi:10.1016/j.rser.2015.04.083

Cong, R., & Drukker, D. M. (2001). Treatment effects model. *Stata Technical Bulletin*, *10*(55).

Cook, S., Silici, L., Adolph, B. & Walker, S. (2015). Sustainable intensification revisited. IIED Issue Paper. IIED, London, pp 1-31

Croft, M. M., Marshall, M.I., & Hallett, G.S. (2016). Market Barriers Faced by Formal and Informal Vendors of African Leafy Vegetables in Western Kenya. *Journal of Food Distribution Research, 47*(3), 49-60.

Dehejia, R. H., & Wahba, S. (2002). Propensity score-matching methods for nonexperimental causal studies. *The review of economics and statistics*, *84*(1), 151-161.

Dick, J., Kaya, B., Soutoura, M., Skiba, U., Smith, R., Niang, A., & Tabo, R. (2008). The contribution of agricultural practices to nitrous oxide emissions in semi-arid Mali. *Soil Use Management*, 24 (292–30).

Godfray, C., Beddington, J., Crate, R., Haddah, L., Lawrence, D., Muir, J., Pretty, J., Robison, S., Thomas, S., & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science* 327: 812–818.

Government of Kenya (GoK). (2014). Kenya National Bureau of Statistics (KNBS). Economic survey report 2014. Government Printers. Nairobi.

van Grünigen, J. W., Vlotho, G. L., Onera, O., van Grünigen, K.J., & van Kessel, C., (2010). Towards an agronomic assessment of N_2O emissions: a case study for arable crops. *European Journal of Soil Science*, 61, 903–913.

Hausman, J. A., & Wise, D. A. (1978). A conditional probit model for qualitative choice: Discrete decisions recognizing interdependence and heterogeneous preferences. *Journal of the Econometric Society*, 403-426.

HCDA. (2014). National horticulture validated report. Kenya: Ministry of Agriculture, Department of Horticultural Crops Development Authority. Government Printer, Nairobi, Kenya.

Heckman, J. J., Ichimura, H., & Todd, P. E. (1997). Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. *The review of economic studies*, *64*(4), 605-654.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80(3), 525-540. doi:10.1016/j.techfore.2012.08.007

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400-411. doi:10.1016/j.landusepol.2014.08.016

Linquist, B., van Groenigen, K. J., Adviento-Borbe, M. A., Pittelkow, C., & van Kessel, C., (2012). An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology*, 18, 194–209.

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *Stata Journal*, *4*, 282-289.

Maddala, G. S. (1986). *Limited-dependent and qualitative variables in econometrics*: Cambridge university press.

Mosier, A. R., Delgado, J. A., Keller, M. (1998). Methane and nitrous oxide fluxes in an acid oxisol in western Puerto Rico: effects of tillage, liming and fertilization. Soil Biol. Biochem. 30, 2087–2098. Mosier, A.R., Halvorson, A.D., Reule, C.A., Liu, X.J.

(2006). Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. *Journal of Environment Quality*, 35, 1584–1598.

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2016). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49, 117-127. doi:10.1016/j.foodpol.2014.06.010

Ngugi I., K., Gitau, R., & Nyoro, J. (2007) Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya: re-governing markets innovative practice series. International Institute for Environment and Development, London

Obura, P., D. Schulze, J. Okalebo, Othieno, C., & Johnston, C. (2010). Characterization of selected Kenyan acid soils. 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World 1–6 August 2010, Brisbane, Australia.

Onium, M., & Manikin, P. (2008) Cataloguing and evaluation of available community/farmers-based seed enterprises on African indigenous vegetables (AIVs) four ECA countries, Entebbe, Uganda

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1), 5-24. doi:10.3763/ijas.2010.0583

Shiferaw, B. A., Okello, J., & Reddy, R. V. (2007). Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices. *Environment, Development and Sustainability, 11*(3), 601-619. doi:10.1007/s10668-007-9132-1

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labour. *Ecological Economics*, 93, 85-93.

The Royal Society. 2009. *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture.* RS Policy Document 11/09. The Royal Society, London.

Vorster, I. H. J, van Rensburg, W. J., Van Zijl, J., & Venter, S. L. (2007). The importance of traditional leafy vegetables in South Africa. *African Journal Food, Agriculture Nutrition and Development,* 7(4):1–13

Wooldridge, J. M., (2010). *Econometric analysis of cross section and panel data*: MIT press.

Yang, R. Y., & Keding, G. B. (2009) Nutritional contributions of important African indigenous vegetables, pp. 105-143. In: Shackleton, C. M., Pasquini, M. W., & Drescher, A. W., (Eds.) African indigenous vegetables in urban agriculture. Earthscan, London.

Summary

African indigenous vegetables (AIVs) have recently gained greater recognition across SSA because of increased awareness on their nutrition and health benefits. This rising consumer consciousness has caused an increase in demand for consumption of AIVs, which in turn has led to increased intensification of AIV production. However, it is not clear whether this AIV intensification is carried out in a sustainable way. This study therefore: (1) evaluated the scale and underlying factors influencing the adoption of sustainable intensification practices (SIPs) (use of improved irrigation systems, integrated soil fertilisation, organic manure and AIV diversification), (2) examined the impacts of SIP adoption on farmers' livelihoods, and (3) assessed economic performance and ecological outcomes of soil fertilisation strategies in order to recommend soil fertility management strategies which optimises production, livelihood and climate trade-offs.

The study begins with an overview and the rationale as well as the outline of the whole thesis in Chapter 1. The data used in the study was basically from two sources: (1) HORTINLEA household panel survey carried out in Kenya between September and November 2016. This survey captured AIV production and marketing data for 2015/2016 production season from 685 households selected from rural and peri-urban areas, and (2) on-farm trials (experiment) which were established in Wangige, Kiambu County to measure N_2O emissions. Inferential statistical analysis using (chi-square test and t-test) was used to test for significant difference on the scale of adoption of SIPs between rural and peri-urban areas in Chapter 2. In addition, SIP adoption intensities were determined by counting the number of SIP adopted by each farming household. Further, a MVP model was employed in determining underlying factors influencing farmers' decisions to select any of the four SIPs considered. A treatment effect model was used in Chapter 3 to evaluate the impacts of adoption on SIPs on farmers' livelihoods. In Chapter 4, cumulative N_2O emission estimates were calculated from the mean flux of the three chambers from each plot and linear interpolation between sampling events using the trapezoidal rule. Gross margin (GM) analysis was used to evaluate economic performance of each treatment, i.e. each soil fertilisation strategy, and was calculated as gross production value minus the variable production costs. Benefit cots ratio (BCR) was estimated by dividing GM by the total variable cost. Livelihood and environmental trade-offs were quantified by calculating N_2OI and N_2OEI.

The assessment of the scale or the level of adoption of SIPs revealed that use of organic manure and AIV diversification were widely adopted across rural and peri-urban production

areas. However, adoption of AIV diversification was significantly higher in rural compared to peri-urban areas. Improved irrigation systems and integrated soil fertility management was rather low, and even significantly lower in rural areas than in peri-urban areas. With regard to adoption intensity, most farmers simultaneously adopted two SIPs with no difference between the rural and peri-urban production environments. However, majority of adopters of three SIPs were from peri-urban areas, suggesting that adoption intensity of SIPs is slightly higher in peri-urban than rural areas. Moreover, complementarities and substitutabilities between SIPs were also identified. For instance, results presented in Chapter 2 show that improved irrigation systems and integrated soil fertility management as well as AIV diversification and organic manure can be adopted jointly because they complement each other. On the contrary, use of integrated soil fertility management and AIV diversification, and the use of organic manure and integrated soil fertility management substitute one another. Complementarities and substitutabilities between SIPs may have policy implications in that a change in policy affecting a single SIP might have a spill over effect on other related SIPs. Therefore, it is important for policy makers to consider such possibility of complementarities and substitutabilities when formulating policies to promote SI of AIV production. The findings of determinants of adoption decisions revealed that market integration strongly influences adoption of all the four SIPs. For instance, farmers who sell AIVs to informal markets significantly adopted improved irrigation systems, use of organic manure and diversifying AIV production. Those selling to formal market outlets were also more likely to adopt integrated soil fertility management, but refrained from solely using manure. Higher household income also significantly influenced adoption of improved irrigation systems, organic manure and AIV diversification. This result highlights the importance of cash in the early stages of adoption decision (i.e. cash is needed to purchase irrigation equipment, drill wells and pay for labour). A peri-urban AIV production environment positively influenced adoption of improved irrigation systems and the use of integrated soil fertility management. This was attributed to the fact that peri-urban farmers have better access to good infrastructure (particularly transport and communications) which enables farmers to access farm inputs, information on new agricultural technologies and lucrative urban market outlets at reduced transaction costs than their counterparts in rural areas. In addition, those farming households with higher education level, own land and belong to a farmer group were more likely to use animal manure. There is also a clear link between access to information on new agricultural technologies and adoption of integrated soil fertility management. Further, male headed farm households and those households with farming as their main occupation were more likely to use improved irrigation systems.

The results from the treatment effect model (chapter 3) revealed that adoption of SIPs significantly increases both incomes with marginal effects of 1.2 and 0.9, respectively. These marginal effects translate to a 14.8% and 9.6% increase in crop and total household income, respectively. For robustness check, impacts of adoption on crop and total household income were also evaluated using endogenous switching regression (ESR) model. The ESR estimates indicates that adoption of SIP increases crop and total household income by 53.2% and 12.9% respectively. Overall, these findings imply that the adoption of SIPs should be encouraged because it improves farmer's livelihoods. Chapter 3 also assessed households' socio-economic, institutional and assets access related factors, in order to capture differential impacts of adoption on crop and total household income. In summary, these results revealed that education level, gender, land size, livestock ownership, land fertility, access to credit and information regarding new agricultural technologies and innovations positive affects one or both incomes.

Chapter 4 presents N_2O emission and economic performance of three soil fertilisation strategies (treatments) and a no nitrogen input–control. The soil fertility strategies evaluated were use of manure, mixed (also referred to integrated soil fertilisation) and inorganic fertilisers (DAP). Results presented in this chapter indicate that emissions from the DAP treatment were significantly higher than those from the three other treatments, which were similar to one another. In addition, emission factors for DAP and mixed treatments were 2.6% and 0.7% respectively, while manure treatment had zero. The significantly higher cumulative N_2O emissions from DAP treatment could be attributed high available N in the soil since DAP had high concentration of NO_3-N in the soil. It is likely that part of this available N was used for plant growth while the remainder was converted to N_2O through denitrification process leading to more emissions. Initial immobilisation and delayed release of N, poor quality of manure (6% N of dry weight) and poor storage methods might have contributed to low emissions from manure and mixed integrated soil fertility management.

Yields from DAP and mixed were significantly higher than those from manure and control, which were similar to one another. Fertilisation from DAP showed the best economic performance in terms of GM, land and labour productivity. In general, the GM from the four soil fertility management varied from 2707.8 to 290.1 USD ha^{-1}, while BCR ranged from 4.6 to 1.7. Net income per labour hour varied from 3.9 to 0.5 USD per labour hour. No N-input plots (control) showed the lowest economic performance. GM, BCR and net income per labour hour from DAP and mixed treatments were similar, but significantly higher than those from manure and control. The most labour intensive soil fertility strategy was the use of manure with labour input of 736 working hours’ ha^{-1}.

The findings of N_2O emission intensities based on crop production and economic efficiency shows that mean N_2OI from the no N-input (control) was the highest followed by DAP, indicating that both were the least climate-smart fertilisation strategies. Manure and mixed fertilisation strategy had significantly lower N_2OI compared to that of control. N_2OEI from the control was significantly higher (3.3 ± 0.6 N_2O-N USD^{-1}) than those from the other three treatments, which were alike. The lowest N_2OEI was from mixed treatment (0.6 ± 0.0 N_2O-N USD^{-1}), while those from DAP and manure were 1.1 ± 0.3; 1.0 ± 0.3 N_2O-N USD^{-1} respectively. In general, these results demonstrate how a choice of indicator (metric) could alter the selection of best-fit soil fertilisation strategies. For instance, when considering N_2O emissions, the highest emissions per unit land area came from DAP, followed by mixed, and lowest from manure and control. However, after N_2O emissions were expressed as a function of yield, mixed and manure treatments performed best (lowest environmental impact, i.e. had lowest N_2OI values). With N_2OEI, however, a different story comes up, mixed treatment had the lowest value. These results suggest that mixed or integrated soil fertility manage strategy optimises economic and environmental performance. Therefore, the conclusions on the selection of which soil management practice is the best fit for achieving the goal of SI (i.e. optimise livelihood and climate trade-offs) may differ depending on the metrics chosen.

The information generated in this study would be helpful to stakeholders, specifically, farmers producing AIV, researchers as well as decision makers in developing efficient policies and programs which targets increased sustainable intensification of AIV production in Kenya and other parts in SSA region. Further, the findings from this study will fill the existing knowledge gap on the scale and underlying factors influencing adoption of SIPs in AIV production, causal effects of adoption of SIPs in farmers’ livelihoods and which soil fertility management strategy for AIV production in peri-urban areas optimizes livelihood and climate trade-offs.

Zusammenfassung

Afrikanisches indigenes Gemüse (AIG) hat in letzter Zeit aufgrund des gestiegenen Bewusstseins für seine ernährungsphysiologischen und gesundheitsbezogenen Vorteile in SSA eine größere Anerkennung erfahren. Dieses steigende Verbraucherbewusstsein hat zu einem Anstieg der Nachfrage nach AIV-Konsum geführt, was wiederum zu einer verstärkten Intensivierung der AIV-Produktion geführt hat. Es ist jedoch nicht klar, ob diese AIG-Intensivierung auf nachhaltige Weise durchgeführt wird. Diese Studie untersuchte daher: (1) den Umfang und die zugrunde liegenden Faktoren, die die Einführung von nachhaltige Intensivierungspratiken (SIPs) (Nutzung verbesserter Bewässerungssysteme, integrierte Bodendüngung, organische Düngung und AIG-Diversifizierung) beeinflussen, (2) die Auswirkungen der SIP-Einführung auf die Lebensbedingungen der Landwirte; und (3) bewertete wirtschaftliche Leistung und ökologische Ergebnisse von Düngestrategien, um Strategien zur Verbesserung der Bodenfruchtbarkeit zu empfehlen, die die Produktion, den Lebensunterhalt und negative Einflüsse auf das Klima optimieren.

Die Studie beginnt mit einem Überblick und der Begründung sowie der Gliederung der gesamten These in Kapitel 1. Die in der Studie verwendeten Daten stammten im Wesentlichen aus zwei Quellen: (1) HORTINLEA-Haushaltspanel-Umfrage, die zwischen September und November 2016 in Kenia durchgeführt wurde. Diese Umfrage erfasst AIG Produktions- und Marketingdaten für die Saison 2015/2016 aus 685 Haushalten, die aus ländlichen und stadtnahen Gebieten ausgewählt wurden, und (2) Feldversuche zur Messung von N_2O-Emissionen, die in Wangige, Kiambu County, auf einem Feld repräsentativ für die kleinstädtische AIV-Produktion durchgeführt wurden. Inferenzstatistische Analyse mit (Chi-Quadrat-Test und T-Test) wurde verwendet, um für signifikante Unterschiede bei der Einführung von SIPs zwischen ländlichen und peri-urbanen Gebieten in Kapitel 2 zu testen. Darüber hinaus wurden SIP-Adoptionsintensitäten durch Zählen der Anzahl der SIP von jedem landwirtschaftlichen Haushalt angenommen. Darüber hinaus wurde ein MVP-Modell verwendet, um die zugrundeliegenden Faktoren zu bestimmen, die die Entscheidung der Landwirte beeinflussten, eines der vier betrachteten SIP auszuwählen. Ein Behandlungseffektmodell wurde in Kapitel 3 verwendet, um die Auswirkungen der Einführung von SIP auf den Lebensunterhalt der Landwirte zu bewerten. In Kapitel 4 wurden kumulative N_2O-Emissionsschätzungen aus dem mittleren Fluss der drei Kammern aus jeder Kurve und linearer Interpolation zwischen Stichprobenereignissen unter Verwendung der Trapezregel berechnet. Die Bruttomarge (GM) -Analyse wurde verwendet, um die wirtschaftliche Leistung jeder Behandlung, d. H. jeder Düngungsstrategie, zu bewerten. Die

GM wurde als Bruttoproduktionswert abzüglich der variablen Produktionskosten berechnet. Die Nutzen-Kosten-Verhältnis (NKV) wurde geschätzt, indem GM durch die gesamten variablen Kosten dividiert wurde. Der Lebensunterhalt und die Umweltentlastungen wurden durch Berechnung von N_2OI und N_2OEI quantifiziert.

Die Bewertung der Größenordnung oder der Verbreitung von SIPs zeigte, dass die Verwendung von organischen Düngemitteln und AIG-Diversifizierung in ländlichen und stadtnahen Produktionsgebieten weit verbreitet war. Die Diversifizierung der AIG war jedoch in ländlichen Gebieten im Vergleich zu Gebieten in Stadtrandgebieten deutlich höher. Verbesserte Bewässerungssysteme und ein integriertes Bodenfruchtbarkeitsmanagement waren eher niedrig und in ländlichen Gebieten sogar deutlich niedriger als in Stadtrandgebieten. Hinsichtlich der Adoptionsintensität haben die meisten Landwirte gleichzeitig zwei SIPs ohne Unterschied zwischen den ländlichen und Peri urbanen Produktionsumgebungen eingeführt. Die Mehrheit der Nutzer von drei SIPs stammte jedoch aus peri-urbanen Gebieten, was darauf hindeutet, dass die Adoptionsintensität der SIPs in Stadtrandgebieten etwas höher ist als in ländlichen Gebieten. Darüber hinaus wurden auch Komplementaritäten und Substituierbarkeiten zwischen SIPs identifiziert. Die in Kapitel 2 vorgestellten Ergebnisse zeigen beispielsweise, dass verbesserte Bewässerungssysteme und integriertes Bodenfruchtbarkeitsmanagement sowie AIG-Diversifizierung und organischer Dünger gemeinsam angenommen werden können, da sie sich ergänzen. Im Gegensatz dazu, ersetzen die Nutzung des integrierten Bodenfruchtbarkeitsmanagements und der AIG-Diversifizierung sowie die Verwendung von organischem Dünger und integriertem Bodenfruchtbarkeitsmanagement einander. Komplementaritäten und Substituierbarkeiten zwischen SIPs können Auswirkungen auf Politikmaßnahmen haben, da eine Änderung der Richtlinie, die sich auf ein einzelnes SIP auswirkt, möglicherweise Auswirkungen auf andere SIPs hat. Daher ist es wichtig, dass politische Entscheidungsträger solche Komplementaritäten und Substituierbarkeiten bei der Formulierung von Strategien zur Förderung der nachhaltigern Intensivierung der AIG-Produktion berücksichtigen. Die Ergebnisse der Determinanten von Adoptionsentscheidungen zeigten, dass die Marktintegration die Einführung aller vier SIPs stark beeinflusst. Zum Beispiel haben Landwirte, die AIVs an informelle Märkte verkaufen, signifikant verbesserte Bewässerungssysteme, organischen Düngereinsatz und eine Diversifizierung der AIG-Produktion eingeführt. Diejenigen, die an formelle Marktstellen verkauften, nahmen auch eher ein integriertes Bodenfruchtbarkeitsmanagement an, verzichteten jedoch darauf, ausschließlich Gülle zu verwenden. Höhere Haushaltseinkommen beeinflussten auch die Einführung verbesserter Bewässerungssysteme, organischen Düngers und AIG-Diversifizierung erheblich. Dieses Ergebnis unterstreicht die Bedeutung von Kapital in den frühen Stadien der Adoptionsentscheidung (d. h. Kapital wird benötigt, um Bewässerungsausrüstung zu kaufen, Brunnen zu bohren und für Arbeit zu bezahlen). Eine stadtnahe AIG-Produktionsumgebung hat die Einführung verbesserter Bewässerungssysteme und die Nutzung eines integrierten Bodenfruchtbarkeitsmanagements positiv beeinflusst. Dies wurde der Tatsache zugeschrieben, dass peri-urbane Bauern einen besseren Zugang zu guter Infrastruktur (insbesondere Verkehr und Kommunikation) haben, was den Landwirten den Zugang zu Betriebsmitteln, Informationen zu neuen Agrartechnologien und lukrativen städtischen Absatzmärkten zu reduzierten Transaktionskosten ermöglicht. Landwirtschaftlichen Haushalte mit höherem Bildungsniveau, eigenem Land und einer Bauerngruppe eher Gülle. Es besteht auch eine klare Verbindung zwischen dem Zugang zu Informationen über neue landwirtschaftliche Technologien und der Einführung eines integrierten Bodenfruchtbarkeitsmanagements. Darüber hinaus nutzten die Haushalte mit männlichen Entscheidern und die Haushalte mit Landwirtschaft als Hauptbeschäftigung eher Bewässerungssysteme.

Die Ergebnisse des Behandlungseffektmodells (Kapitel 3) zeigten, dass die Einführung von SIPs beide Einkommen mit marginalen Effekten von 1,2 bzw. 0,9 signifikant erhöht. Diese marginalen Effekte führen zu einem Anstieg der Ernteerträge um 14,8% bzw. 9,6%. Zur Überprüfung der Robustheit wurden auch die Auswirkungen der Adoption auf die Ernte und das gesamte Haushaltseinkommen anhand des Endogenen Switchen Regression (ESR)-Modells bewertet. ESR-Schätzungen zeigen, dass die Einführung von SIP das Ernte- und Haushaltseinkommen um 53,2% bzw. 12,85% erhöht. Insgesamt deuten diese Ergebnisse darauf hin, dass die Einführung von SIP gefördert werden sollte, da dies die Lebensbedingungen der Landwirte verbessert. Kapitel 3 bewertete auch die sozioökonomischen, institutionellen und vermögenszugangsbezogenen Faktoren der Haushalte, um die unterschiedlichen Auswirkungen der Adoption auf das Ernte- und Gesamteinkommen der Haushalte zu erfassen. Zusammenfassend zeigen diese Ergebnisse, dass Bildungsniveau, Geschlecht, Landgröße, Viehbestand, Landfruchtbarkeit, Zugang zu Krediten und Informationen über neue Agrartechnologien und Innovationen positiv auf eines oder beide Einkommen wirken.

In Kapitel 4 werden die N_2O-Emissionen und die wirtschaftliche Leistung von drei Bodenbearbeitungsstrategien (Behandlungen) und einer Stickstoffeinfuhrkontrolle vorgestellt. Die bewerteten Bodenfruchtbarkeitsstrategien waren: Verwendung von Gülle, gemischte (auch als integrierte Bodendüngung bezeichnet) und anorganische Düngemittel (DAP). Die Ergebnisse in diesem Kapitel zeigen, dass die Emissionen aus der DAP-Behandlung signifikant höher waren als die der drei anderen Behandlungen, die einander ähnlich waren. Darüber hinaus betrugen die Emissionsfaktoren für DAP und Mischbehandlungen 2,6% bzw. 0,7%, während die Mistbehandlung null war. Die signifikant höheren kumulativen N_2O-Emissionen aus der DAP-Behandlung könnten dem hohen verfügbaren N im Boden zugeschrieben werden, da DAP eine hohe Konzentration von NO_3-N im Boden aufwies. Es ist wahrscheinlich, dass ein Teil dieses verfügbaren N für das Pflanzenwachstum verwendet wurde, während der Rest durch Denitrifizierungsprozess zu N_2O umgewandelt wurde, was zu mehr Emissionen führte. Anfängliche Immobilisierung und verzögerte Freisetzung von N, schlechte Dungqualität (6% N Trockengewicht) und schlechte Lagerungsmethoden könnten zu geringen Emissionen aus Gülle und gemischtem integriertem Bodenfruchtbarkeitsmanagement beigetragen haben.

Die Erträge aus DAP und Mischbehandlung waren signifikant höher als die aus Mist und Kontrolle, die einander ähnlich waren. Düngung von DAP zeigte die beste wirtschaftliche Leistung in Bezug auf GM, Land und Arbeitsproduktivität. Im Allgemeinen variierte das GM aus den vier Bodenfruchtbarkeitsmanagements von 2707,8 auf 290,1 USD ha^{-1}, während BCR zwischen 4,6 und 1,7 lag. Das Nettoeinkommen pro Arbeitsstunde variierte von 3,9 bis 0,5 USD pro Arbeitsstunde. Keine N-Input-Felder (Kontrolle) zeigten die niedrigste wirtschaftliche Leistung. GM, NKV und Nettoeinkommen pro Arbeitsstunde aus DAP und Mischbehandlungen waren ähnlich, aber signifikant höher als diejenigen aus Dung und Kontrolle. Die arbeitsintensivste Bodenfruchtbarkeitsstrategie war die Verwendung von Gülle mit einem Arbeitseinsatz von 736 Arbeitsstunden ha^{-1}.

Die Befunde der N_2O-Emissionsintensitäten auf der Grundlage der Pflanzenproduktion und der wirtschaftlichen Effizienz zeigen, dass der mittlere N_2OI-Wert ohne N-Input (Kontrolle) am höchsten war, gefolgt von DAP, was darauf hindeutet, dass beide die am wenigsten klimaschädlichen Düngestrategien waren. Dünger- und Mischdüngungsstrategie wiesen im Vergleich zur Kontrolle einen signifikant niedrigeren N_2OI auf. N_2OEI aus der Kontrolle war signifikant höher ($3,3 \pm 0,6$ N_2O-N USD^{-1}) als diejenigen aus den anderen drei Behandlungen, die gleich waren. Das niedrigste N_2OEI stammte aus einer gemischten

Behandlung (0,6 ± 0,0 N_2O-N USD^{-1}), während diejenigen aus DAP und Dung 1,1 ± 0,3 betrugen; 1,0 ± 0,3 N_2O-N USD^{-1} jeweils. Im Allgemeinen zeigen diese Ergebnisse, wie eine Wahl des Indikators (metrisch) die Auswahl der am besten geeigneten Bodendüngungsstrategien verändern könnte. Wenn beispielsweise N_2O-Emissionen in Betracht gezogen werden, stammen die höchsten Emissionen pro Flächeneinheit von DAP, gefolgt von gemischt und am niedrigsten von Dünger und Kontrolle. Wenn die N_2O-Emissionen jedoch als eine Funktion der Erntemenge ausgedrückt wurden, wurden Misch- und Dungbehandlungen am besten durchgeführt (geringste Umweltbelastung, d. h. sie hatten die niedrigsten N_2OI-Werte). Bei N_2OEI hatte jedoch Mischbehandlung den niedrigsten Wert. Diese Ergebnisse deuten darauf hin, dass eine gemischte oder integrierte Strategie zur Steuerung der Bodenfruchtbarkeit die wirtschaftliche und ökologische Leistung optimiert. Daher können die Schlussfolgerungen hinsichtlich der Auswahl, welche Bodenmanagementpraxis am besten zur Erreichung des Ziels von SI geeignet ist (d. h. Optimierung von Lebensunterhalt und klimaschädlicher Wirkung), in Abhängigkeit von den gewählten Messgrößen abweichen.

Die in dieser Studie generierten Informationen wären hilfreich für Stakeholder, insbesondere Landwirte, die AIG produzieren, Forscher sowie Entscheidungsträger bei der Entwicklung effizienter Strategien und Programme, die auf eine verstärkte nachhaltige Intensivierung der AIV-Produktion in Kenia und anderen Teilen der SSA-Region abzielen. Darüber hinaus werden die Ergebnisse dieser Studie die bestehende Wissenslücke hinsichtlich der Größenordnung und der zugrundeliegenden Faktoren, die die Einführung von SIP in die AIV-Produktion beeinflussen, kausale Auswirkungen der Einführung von SIPs auf die Lebensgrundlage der Landwirte und die Strategie der Bodenfruchtbarkeitsverwaltung für AIG-Produktion in Stadtrandgebieten füllen.

Autobiography

Barnabas Kiplagat Kurgat was born on January 2, 1983 in Tulon, Nandi Central District in Nandi County. After his primary education at Kiptenden Primary School (1988-1997), Barnabas joined Kapsabet Boys High School (1998-2001) for his secondary education. After high school, he was employed as a teacher at Tulon Secondary School where he taught for one term. In 2003, he joined Egerton University, Njoro Campus to pursue a Bachelor of Science degree in Natural Resource Management from which he graduated with 2nd Class Honours Upper Division on November 24, 2007. After graduating, Barnabas was employed in 2008 as an environmental officer at Universal Work Health and Safety Consultancy in Nakuru. In 2009, he was awarded a scholarship for a Master’s degree at Hohenheim University under the cross-continental network for sustainable adaptation of grassland systems vulnerable to climate change (GrassNet) research project funded by DAAD (Deutscher Akademischer Austausch Dienst). Barnabas graduated with a Master’s degree in Agricultural Sciences in the Tropics and Sub-tropics (Natural Resource Management Option) on November 14, 2011. His M.Sc. thesis was entitled: “Relationship between above-ground vegetation cover types and soil organic carbon stocks in the rangelands of Northern Kenya”. After his M.Sc., he went back to Kenya where he joined his colleagues at the Universal Work Health and Safety Consultancy. In May 2013, Barnabas was employed as an Assistant Lecturer at Laikipia University where he worked until December 2014 when he was awarded a PhD Scholarship under the HORTINLEA research project funded by the German Federal Ministry of Education and Research, and the German Federal Ministry for Education Cooperation and Development. Consequently, Barnabas enrolled as a PhD candidate at Humboldt Universität zu Berlin in 2015 where he pursued his studies culminating to this thesis. His hobbies include reading, research, listening to music, partying and adventuring nature.

List of publication

Published papers

1. **Kurgat**, **B.K**., Ngenoh, E., Bett, H., Stöber, S., Mwonga, S., Lotze-Campen, H., Rosenstock, S. (2018) Drivers of Sustainable Agricultural Practices in African Indigenous Vegetable Production in Kenyan Peri-urban and rural areas. International Journal of Agricultural Sustainability, 16:4-5, 385-398.
2. **Kurgat, B.K**., Stöber, S., Mwonga, S., Lotze-Campen, H., Rosenstock, S. (2018). Livelihood and climate trade-offs in Kenyan peri-urban vegetable production. Agricultural Systems, 160, 79-86.
3. Stöber, S., Chepkoech, W., Neubert, S., **Kurgat**, B., Bett, H., & Lotze-Campen, H. (2017). Adaptation Pathways for African Indigenous Vegetables' Value Chains. 413-433. doi:10.1007/978-3-319-49520-0_25
4. Omboga, S., **Kurgat, B.K**., Cheshari, C.E., Rotich, M. K., Mavura, J.M. (2014), "Determination of dissolved constituents and Ionic Strength of Saline Water: A Case Study of Lakes; Nakuru, Bogoria-Kenya and Nata Salpant Sanctuary –Botswana'', *Journal of Natural Sciences Research*, vol. 4 (18), 107-112 pp
5. Cheruiyot, M. K., **Kurgat, B. K.,** Muturi, W., Kosgey, I. S. (2014), "Environmental Effects of Urban Cattle Keeping in Nakuru Municipality, Kenya", *Journal of Natural Sciences Research'',* vol. 4 (18), 113-119pp
6. Cheruiyot, M. K., **Kurgat, B. K.,** Muturi, W., Kosgey, I. S. (2014), "Assessment of Urban Cattle Keeping Patterns and Waste Disposal Mechanisms in Nakuru Municipality, Kenya", *Journal of Natural Sciences Research*, vol. 4 (16), 138-144 pp
7. **Kurgat, B.K**., Golicha, D., Giese, M., Kuria, S.G., Asch, F. (2014), "Relationship between above ground vegetation cover types and soil organic carbon stocks in the rangelands of Northern Kenya", *Journal of Livestock Research and Rural Development,* Vol. 26, article #162. Available online www.lrrd.org/lrrd26/9/kur26162.html

Manuscript(s) under review

8. **Kurgat**, **B.K**., Ngenoh, E., Bett, H., Stöber, S., Mwonga, S., Lotze-Campen, H., Rosenstock, S. (2018) Impacts of sustainable intensification of vegetable production on farmers' livelihoods in Kenya, International Journal of Agricultural Sustainability, (**submitted**)

Publications in Conference Proceedings

1. **Kurgat, B.K**., Stöber, S., Neubert, S., Bett, H., Chepkoech, W., Lotze-Campen, H. (2015). Potential of African Indigenous Vegetables to Contribute to Climate-Smart Food Systems. In: International Research on Food Security, Natural Resource Management and Rural Development, Tropentag, September, 16-18, 2015, Berlin Germany (poster)
2. Chepkoech, W., Stöber, S., Neubert, S., Bett, H., **Kurgat, B.K**., Lotze-Campen, H. (2015) Vulnerability to Climate Change of African Indigenous Vegetable Farmers in Selected Agro-Climatic Zones of Kenya. In: International Research on Food Security, Natural Resource Management and Rural Development, Tropentag, September, 16-18, 2015, Berlin Germany (poster)
3. **Kurgat, B.K**, Muithui, L. W., Kosgey, I.S. (2014), "The Role of Women in Pastoral Communities: Implications for Food Security in Arid and Semi-arid Lands of Kenya", African Universities: Crises, Transformation and Opportunities, Proceedings of 2nd International Conference of Laikipia University, on 20th-23rd May, 2014.
4. **Kurgat, B.K**., Golicha, D., Giese, M., Kuria, S.G., Asch, F. (2014), "Relationship between above ground vegetation cover types and soil organic carbon stocks in the rangelands of Northern Kenya", African Universities: Crises, Transformation and Opportunities, Proceedings of 2nd International Conference of Laikipia University, on 20th-23rd May, 2014.
5. Golicha, D., **Kurgat, B.K.**, Richter, U., Kaufmann, B. (2012), "Use of Solar Backpack to capture grazing itineraries: the case of Gabra pastoralists in northern Kenya", Proceedings of Animal Production Society of Kenya annual symposium. April, 11-12, 2012, Nyeri, Kenya
6. Golicha, D.D., Richter, U., **Kurgat, B.K.**, Kuria, S.G., Hülsebusch, C., Kaufmann B. (2011) Assessment of Decision Making in Grazing Management: The Case of Gabra Pastoralists of Northern Kenya. In: Development on the Margin, Tropentag, October 5-7, 2011, Bonn, Germany.

Acknowledgement

I am very grateful for the opportunity given to me by HORTINLEA to undertake my PhD studies. I extend special thanks to my professors and supervisors: Prof. Dr. Hermann Lotze-Campen, Prof. Dr. Samuel Mwonga, Dr. Silke Stöber, Dr. Todd Rosenstock and Dr. Hillary Bett for their valued guidance, support and direction during the development of this PhD research. Their academic critiques and extensive discussions highly inspired my writing of this thesis. They were all encouraging throughout my PhD research, and even provided a lot of solace when everything seemed to be falling apart. I owe them a great deal of gratitude for their academic mentorship. Special thanks goes to Dr. Susanne Neubert for offering me and my fellow HORTINLEA PhD student Winifred Chepkoech office space at the Centre for Rural Development (Seminar für Ländliche Entwicklung (SLE) during our entire stay in Berlin. I am equally thankful to Dr. Todd and ICRAF for allowing me to use their facilities while conducting on-farm experiment in Kiambu. Special thanks also goes to Egerton University for providing immense logistical support during household surveys and data collection, part of which was used in this thesis.

I am indebted to my wife, Trizah for her understanding and putting up with my constant absence when I was away in the field, library or in Berlin. This gratitude must also be extended to my sweet little daughter, Shanell Jepkosgey Kurgat for putting up with her "non-existing father" during the months I was away from home. The family of Kap Chemwor (Kap Chepchocho) deserves appreciation for bestowing on me the mantle of education in the family. I am indebted to my mother, Rael Jepmanyur Lalang and my brothers for their support and constant prayers all throughout my studies.

I would like to thank my colleague Mr. Evans Ngenoh for his support especially when I first started working on household survey data. Special thanks also goes to my colleague and office mate Winifred and the SLE team who made my stay in Berlin wonderful and free of homesickness. Caroline deserves a special thanks for stepping in to coordinate the activities of SP8. I may not be able to mention everybody by name who contributed, in one way or another, to the success of my PhD and my entire education in general. I salute you all and say a big thank you. Thanks to Almighty God for making it all possible.